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CATALOGUE OF INFRARED SPECTRA OF FOSSIL RESINS (AMBERS)

I NORTH AND SOUTH AMERICA[1]

BY

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FOSSIL resins are of interest to the mineralogist, palaeontologist, botanist, entomologist, chemist, and archaeologist, but, because their study straddles these many fields, they have not received comprehensive attention from any quarter. During the 19th Century, mineralogists described and named well over 100 fossil resins, mostly of European origin, and botanists and entomologists studied plant and insect inclusions, primarily in Baltic amber. In the New World there are no fewer resins, but, since they have been studied by biologists rather than mineralogists, few have been given names.

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Even now, the only reasonably inclusive listing of fossil resin occurrences, restricted largely to the named varieties, are to be found in the back pages of standard works on mineralogy or mineral chemistry, such as those of Dana (1895), Hintze (1933) or Doelter and Leitmeier (1930). Their description by standard mineralogical procedures, which are ill suited to complex, largely non-crystalline, organic materials, does not provide an acceptable basis for classification. It is indeed no exaggeration to say that fossil resins have not yet been ordered into a classification system. Mineralogical compendia make broad distinctions between "families" containing or lacking succinic acid, sulfur or nitrogen, but these superficial criteria do not reflect any meaningful relationship in establishing a natural classification system.

Paclt (1953) has suggested a system ordered by geologic age and botanical origin. The former criteria, unfortunately, have had to be based on meager and scattered published evidence. Most often, the botanical origin, which is based on associated fossil plant remains, is indicated without supporting evidence because of lack of available data in the literature. Botanical source unquestionably is the most significant basis for classification of fossil resins, since they are plant products the chemical composition of which is genetically controlled (Mirov, 1961; 1967). Also study of the botanical source of fossil resin through geologic time provides an opportunity to observe evidence of biochemical evolution within the populations that produce the resin. Resins from some populations appear to have a relatively stable composition through millions of years, whereas others have changed considerably. The determination of the origin of resin, however, is a difficult task because of the changes which resins undergo in the process of fossilization. Resins polymerize with age, presumably by a free-radical mechanism. As a result, the fossil product is a macromolecule of high molecular weight, largely insoluble, and not amenable to most of the usual methods of attack used in elucidating the structures of organic compounds.

We have found infrared spectroscopy a useful technique in botanical investigations of both fossil and modern resins at Harvard University and in the classification of fossil resins for archaeological ends at Vassar College. We now hope to use our diverse interests and competences to undertake the large task of a systematic study of fossil resins. The goal is to classify them first relatively, i.e. sorting them into groups of resins which share the same gross composition as revealed by their infrared spectra. We eventually expect to determine their botanical source by comparison of the infrared spectra of recent and fossil resins corroborated wherever possible by paleobotanical data. Some results of this collaboration have been published previously (Langenheim and Beck, 1965).

Infrared spectroscopy is useful particularly in comparing fossil and recent resins because polymerization preserves all simple functional groups of the recent resin with the exception of carbon-carbon double bonds. Also skeletal frequencies are damped but not usually extinguished completely. Thus, a similarity remains between the spectra of recent and fossil resins in that certain absorption peaks can be matched one-to-one, although the intensity of these peaks is usually much weaker in the fossil resins than it is in the recent ones, especially at longer wave lengths.

Over the past few years, we have prepared infrared spectra of well over a thousand fossil resins and several hundred present-day resins. It now seems appropriate to make this large body of evidence accessible to interested research workers in the form of a catalogue which will be divided into three sections: I, North and South American; II, Europe; III, Asia and Africa. A fourth section probably will present spectra of resins from living plants.

We have attempted to procure as many specimens as possible of each kind of fossil resin from the leading collections of the New and Old World. Samples used in this section were obtained from the Harvard University Botanical Museum Paleobotanical Collections; Harvard University Mineralogical Collections; Harvard University Entomological Collections; Museum of Paleontology, University of California at Berkeley, United States National Museum (Smithsonian), New York Museum of Natural History and Museum für Naturkunde, East Berlin.

Since infrared spectroscopy is not yet a method widely used by botanists and mineralogists, we will here include a brief discussion of the major absorption bands of the fossil resins and their significance. Infrared radiation is absorbed by matter to provide the necessary energy for the motion of atoms within a molecule. These motions may be relatively simple (stretching and bending of individual bonds between two atoms) or they may be very complex (involving larger portions of the carbon skeleton of the molecule). The simpler motions predominantly lead to absorption at low wave lengths (2.5–8 μ; 4000 to 1250 cm^{-1}). Because they are essentially independent of the rest of the molecule, their absorption bands are remarkably stable in position and are readily assigned to specific functional groups. Thus, the first absorption band of fossil resins at 2.9 μ (3500 cm^{-1}) is due to the stretching of hydrogen-oxygen bonds; the bending motion of these bonds causes absorption at about 6.1 μ (1650 cm^{-1}).

Some of the hydroxl groups responsible for these two bands without doubt pre-exist in the resin, but others are the result of atmospheric water vapor taken up by the sample in the course of its preparation (Beck *et al.*, 1966). The group of more or less well resolved absorptions near 3.4 μ (2950 cm^{-1}) is due to the stretching of carbon-hydrogen bonds; the bending motions of these same bonds lead to absorption near 6.8 μ (1470 cm^{-1}) and 7.25 μ (1380 cm^{-1}).

The remaining prominent band in the lower region is due to the stretching of carbon-oxygen double bonds. This so called carbonyl band usually occurs near 5.8 μ (1700 cm^{-1}) in the fossil resins. All these absorption bands are almost uniformly typical of all fossil resins and, therefore, of limited diagnostic value. Only the position, intensity, and resolution of the carbonyl band show significant variation.

The upper region of the spectra (8 to 16 μ; 1250 to 625 cm^{-1}) is more difficult to interpret in terms of chemical structure, but it is nevertheless more useful than the lower region because it shows greater variety. Of prime importance is the region between 8 and 10 μ (1250 and 1000 cm^{-1}), where absorption is due to carbon-oxygen single bonds. Since these vibrations are substantially influenced by the carbon skeleton of the entire molecule, it is rarely possible to assign these bands to very specific structural features. However, as a kind of fingerprint of a fossil resin, this upper region is the one that we most often rely upon to classify resins into groups which are not only recognizable as having similar basic structures, but which we can increasingly relate to recent resins, and thus obtain important evidence about the botanical origin of the fossil resins.

Absorption bands above 10 μ (1000 cm^{-1}) are, in general, still more difficult to assign and must therefore be used mainly as fingerprints. But there are a few major exceptions. Bending motions of hydrogen atoms attached to unsaturated carbon atoms lead to absorptions which are highly characteristic and which yield useful structural information. In the fossil resins, the most important of these is the sharp band near 11.3 μ (885 cm^{-1}) which can be attributed to out-of-plane bending of the two hydrogen atoms of a terminal methylene group. The presence of this band in the spectrum of a fossil resin is of particular interest, because it is also a feature of a number of resin acids which have been isolated from recent resins (agathic acid, copalic acid, catavic acid, eperuic acid). The absence of this band in fossil resin spectra, however, must be interpreted with caution, since terminal methyl groups are easily oxidized. The lack of an 11.3 μ (885 cm^{-1}) band in the spectrum of a fossil resin may, therefore, indicate either that the resin never had a terminal methylene group or that this group has been oxidized as a result of long exposure. The hydrogen atoms attached to aromatic rings also cause easily recognizable absorptions in the upper regions. They are rare in fossil resins, but, when they occur, they permit immediate assignment of the resin to the few botanical sources characterized by aromatic components.

All of the spectra were made from amber in the solid state which was dispersed in potassium bromide pellets (Langenheim and Beck, 1965; Beck *et al.*, 1965). The Perkin Elmers Model 137 spectrophotometer was used for the samples reported in this section.

The spectra curves reproduced here can, of course, be only a small fraction of those now recorded in both of our laboratories. To make the selection, we have compared all the spectra of each species or variety in order to choose a few spectra which best represent the group as a whole. In addition, we have included spectra of special interest since they show features not shared by all members of the group.

We should like to warn researchers not to put too much weight on a single infrared spectrum of any fossil resin. Resins are mixtures of appreciable heterogeneity, and the small samples used to prepare spectra may well differ significantly in composition, even when taken from a single specimen. It is always advisable to run two or more spectra of a given specimen and to rely only on those features which are common to all or, at least, to most spectra.

Relatively few of the North and South American ambers have been characterized chemically or physically and assigned mineralogical species names, as numerous of the European ambers have been. In some instances, however, paleobotanical remains of considerable significance in determining the botanical source of the amber have been reported in New World deposits. For this reason, botanical information regarding the kinds of trees that might have produced the amber, in addition to the manner in which the resin may have been produced, have received particular attention in this presentation. Confusion regarding stratigraphic data and, hence age assignments of the amber-bearing strata, are discussed where relevant to an understanding of the rapid evolutionary changes which occurred in some of the possible resin-producing components of Cretaceous floras in particular. Spectra of modern resins will be compared with those of ambers in some cases. Only general comments regarding the origin of the amber will be made, however, since this paper is designed primarily as a catalogue. Detailed discussion of botanical origin will be presented elsewhere.

CRETACEOUS AMBER

Amber from Cretaceous beds have been reported in considerable amounts from the Kuk River drainage of the Alaskan Arctic Coastal Plain, from the beach of Cedar Lake, Manitoba, Canada, and from numerous occurrences along the Atlantic Coastal Plain from Massachusetts to South Carolina. Also a small amount has been recorded from Baja, California, Mexico. Spectra have been made from specimens from the above localities. Although amber has also been noted to occur in Cretaceous rocks from Hardin County, Tennessee (Ross, 1956), Ellsworth County, Kansas (Schoewe, 1942), the Black Hills of South Dakota, Eagle Pass, Texas, Mt. Diablo, California, as well as other localities, samples of these have not been available as yet for analysis.

The Alaskan amber will be discussed first because its stratigraphic relations and associated plant fossils have been investigated more intensively than for other Cretaceous ambers. These studies provide background for interpretation of the botanic source in terms of the infrared spectra.

Alaskan Amber

Amber is widespread in Upper Cretaceous coal and carbonaceous shales along the Kuk River drainage (Kuk, Ketik and Kaolak Rivers) of the Alaskan Arctic Coastal Plain (Langenheim, Smiley, and Gray, 1960; Smiley, 1966). Reworked amber occurs also ubiquitously in Pleistocene beds and along recent stream deposits in this region. Several lines of evidence indicate that these Cretaceous amber-bearing beds are of non-marine origin, and age determinations rest entirely on the abundant plant megafossils and microfossils. The older Kuk flora, characterized by ferns of varied kinds and a mixture of primitive and modern conifers, is considered Cenomanian (earliest stage in the Upper Cretaceous) in age (Smiley, 1966); only a few amber samples were found in these strata. More amber occurred in the Ketik beds to which Smiley assigns a Turonian age. These beds contain the earliest record of abundant and varied angiosperms and the dominant Ketik conifers are modern types referable to extant genera in such families as Taxodiaceae (*Sequoia*, *Sequoiadendron*, ? *Taxodium* and *Juniperus*), Pinaceae (*Pinus*, *Picea* and ? *Larix*) and Taxaceae (*Cephalotaxus* and ? *Torreya*). Most of the amber occurred in association with the Kaolak flora which Smiley designates as Senonian in age. It is characterized by taxodiaceous conifers (*Sequoia*, *Sequoiadendron* and ? *Taxodium*) and ? *Torreya* in the Taxaceae. Gray (Langenheim, *et al.*, 1960) noted an abundance of conifer pollen in this flora with taxodiaceous pollen the dominant type. Pine and spruce pollen also occurred frequently, but the rarity of megafossils suggests that the latter conifers may have inhabited slopes or uplands some distance from lowland depositional sites. Langenheim *et al.* (1960) concluded that the source of this amber was taxodiaceous trees growing close to lakes, coastal swamps or other water bodies from the evidence: 1) the amber has always been found with abundant taxodiaceous remains, 2) the pinaceous pollen was derived from upland sources.

This Alaskan amber has been described neither chemically nor physically and has not been given a mineralogical name. Some of the material is transparent, although much is opaque. The clear amber varies in color from light yellow to red, deep golden brown and almost black. The opaque material varied commonly from a beige to molasses color. Most of the transparent amber is crack-free and has a conchoidal to subconchoidal fracture, whereas the opaque amber is commonly granular. Langenheim *et al.* (1960) indicate that most clear pieces do not contain inclusions, although small bubbles and/or small plant fragments are abundant in some specimens. Most unbroken specimens are small (one-eighth inch in diameter) teardrop masses, subcylindrical pieces up to one-fourth inch in diameter or irregularly mammillary blobs. The teardrops may have dropped from the trunk or branches, and the cylinders may have broken from hardened runnel of resin attached to the surface of a branch. All of these shapes tend to demonstrate resin hardened in the atmosphere. Several occurrences of amber in coal with woody texture, however, suggest that at least part of the amber was derived from resin within the trunk of tree and thus not in a position to trap insects or wind-blown plant debris.

Twenty-two spectra were run of Alaskan amber representing samples varying in color and other physical properties. Nineteen specimens were from the Kaolak River and three from the Ketik River localities; none were available from the Kuk River. Most of these collections were from placer deposits, although at two localities the amber was collected *in situ*. All of the material is from the collections of the Museum of Paleontology, University of California at Berkeley. Three patterns appeared among the 22 spectra run (Plates XIV and XV). The most typical pattern is Type II (H-332); 15 spectra are of this kind. The spectra typical of amber from the Raritan formation from Kreischerville, Staten Island, New York, is similar to Alaska Type II in the carbon skeleton. Type I (H-313) is a more generalized pattern (i.e., more flattened with less pronounced bands) and is represented by three spectra. Type III (H-318 on Plate XV) occurs only in two spectra but is quite similar in the carbon skeleton to that of the amber from the Upper Patapsco Formation from Washington, D.C. There are, however, differences between the pairs Alaska

II and Kreischerville, on the one hand, and Alaska III and Washington, D.C., on the other, in the intensity and resolution of the carbonyl band. The 11.3 μ (855 cm^{-1}) band is most pronounced in Alaska II and Washington, D.C. (H 173 on Plate XV).

Spectra of resin from various living members of the Taxodiaceae and Pinaceae are being run presently to see if correlation can be established with these Alaskan types. The Taxodiaceae are of particular interest, since associated plant remains with the Alaskan amber point to this possible origin. As yet, however, relation of this amber to either members of the Pinaceae or Taxodiaceae is not evident, but further investigation of the modern resins is necessary.

Atlantic Coastal Plain Amber

Amber for spectral analysis has been obtained from twelve localities along the Atlantic Coastal Plain from Massachusetts to South Carolina (Fig. 1). In most cases, the amber was reported to occur in Potomac, Raritan or Magothy beds. Controversy has existed regarding the age of these stratigraphic units (Spangler and Peterson, 1950; Dorf, 1952; Steeves, 1959). Recent palynological studies, however, have essentially confirmed age assignments previously based on plant megafossils (Berry, 1909, 1910, 1911a,b,c, 1914, 1916 *et al.*; Dorf, 1952).

The Potomac Group is the basal unit of the Atlantic Coastal Plain Cretaceous sequence in Maryland, Delaware and Virginia. It typically underlies the Raritan and Magothy Formations in Maryland and Delaware but is absent to the north in New York, New Jersey and Massachusetts, where the Raritan is the oldest Cretaceous unit. The Potomac Group appears to be entirely Lower Cretaceous in age (Brenner, 1963), with the Patuxent Formation being Barremian, the Arundel Formation

CRETACEOUS

I	Alaska (Arctic Coastal Plain)	22
II	Manitoba, Canada (Cedar Lake)	11
III	Atlantic Coastal Plain	
	1. Kreischerville, New York	7
	2. Martha's Vineyard, Massachusetts	1
	3. Harrisonville, New Jersey	2
	4. Cliffwood, New Jersey	1
	5. Bordentown, New Jersey	3
	6. Roebling, New Jersey	11
	7. Kincora, New Jersey	3
	8. Pemberton, New Jersey	2
	9. St. Georges, Delaware	1
	10. Washington, D.C.	2
	11. Magothy River, Maryland	5
	12. Charleston, South Carolina	3
IV	Baja California, Mexico	4

EARLY TERTIARY

V	Seattle, Washington	5
VI	Dominican Republic	7
VII	Chiapas, Mexico	30
VIII	Pará, Brazil	2

UNKNOWN AGE

IX	Guayaquil, Ecuador	3
X	Girón, Colombia	6
XI	Medellín, Colombia	6
XII	Cañon Diablo, Arizona	1
XIII	Greenland	2
XIV	Montana	9

Number of spectra for all localities are indicated.

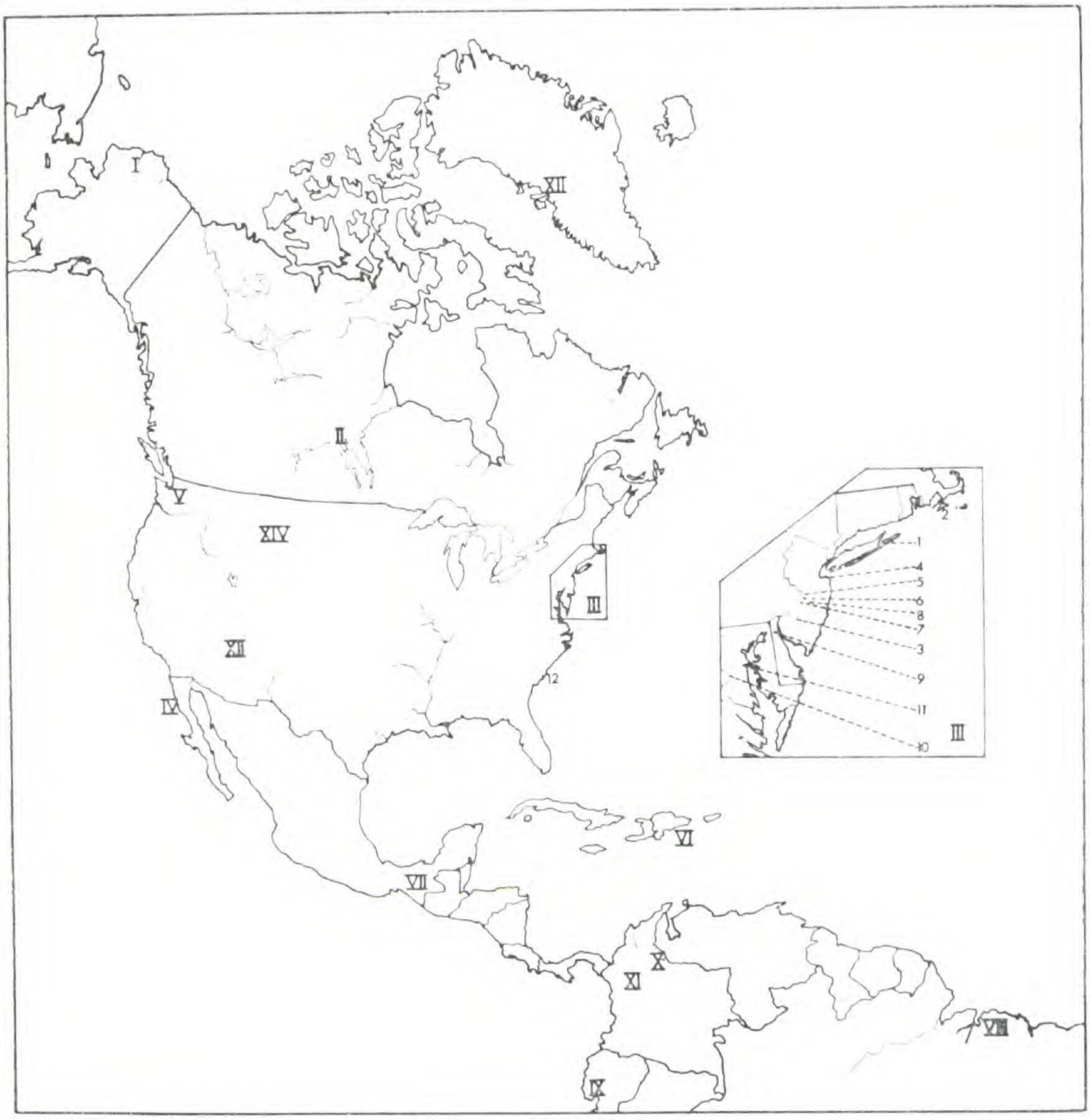

FIGURE I. Location of samples of amber in North and South America from which infrared spectra were run (see explanation on opposite page).

being Aptian, and the Patapsco Formation being restricted to the Albian Stage.

The Raritan Formation, on the other hand, is Upper Cretaceous (Cenomanian-Turonian Stages), according to the palynological investigations of Groot, Penny and Groot (1961) and Kimyai (1966). The overlying Magothy Formation is Turonian-Coniacian (Early Senonian) in age (Groot, Penny and Groot, 1961 and Stover, 1964).

It is impossible to sort out the stratigraphic difficulties for most of the Atlantic Coastal Plain amber deposits from the available literature. It is most important to be aware of the age differences of these deposits, however, and possible confusion regarding them. The age is particularly significant in regard to change in floras and seemingly rapid evolution of coniferous elements that could have been the amber producers. Although angiosperms were rapidly evolving during this time, none except *Liquidambar* are known to have been resin-producing plants.

Washington, D.C. Amber

A single sample of amber from the Upper Patapsco Formation was collected by J. Doyle from the corner of Branch Ave. and O Street SE, Washington, D.C. The amber came from a clay associated with a lignite bed at the top of typical Patapsco clays (Lower Cretaceous, Albian Stage) which are directly overlain by cross-bedded sands thought to be Upper Cretaceous by C. F. Withington (Doyle, 1966). Doyle analyzed the plant microfossils from these beds and found a typical Upper Patapsco assemblage as established by Brenner (1953). Brenner's palynological studies indicate that the gymnosperms of the Potomac forest included members of the Podocarpaceae, Araucariaceae (including *Araucariacites australis* Cook., which is comparable to modern *Araucaria* and

Agathis), Pinaceae and the Cupressaceae-Taxodiaceae complex. Particularly abundant in some localities is *Inaperturopollenites dubius* (Potonie and Venitz) Thomson and Pflug, which is considered to be a member of either the Taxodiaceae or Cupressaceae. *Brachyphyllum-Pagiophyllum* represented other common coniferous families which are now extinct. Brenner further states that these Potomac forests were probably similar in character to the warm-temperate gymnosperm and fern forests of New Zealand today. In these forests, Podocarpaceae and Araucariceae are the dominant trees with a luxuriant growth of ferns characterizing the understory. He adds, however, that the presence of cycads and schizeaceous plants suggests more tropical conditions than exist in present New Zealand forests.

Two spectra were run from a single piece of amber from this O Street sample. The spectra are similar and represented by H 173 (Plate XV). This spectrum resembles also Type III from Alaska (Plate XV).

Kreischerville Amber

Hollick (1905) reported considerable quantities of amber from a Cretaceous deposit at Kreischerville, Staten Island, New York. He stated that the beds were an eastward extension of the Amboy Clay and sand series of New Jersey and thus included in the Raritan formation. He further continued that they were "middle Cretaceous in age and approximately equivalent of the Cenomanian of Europe. . ." Hollick and Jeffrey (1909) indicated that both the Raritan and Cliffwood (Magothy) Formations were present at Kreischerville but that only the Raritan beds here were plant-bearing. Unfortunately, the stratigraphic position of the Kreischerville deposits has not been investigated recently.

The amber occurs in strata containing closely packed masses of leaves, twigs and fragments of lignite and charred wood. Most of it was distributed irregularly in the matrix of relatively thick accumulations of comminuted lignite. The amber occurs commonly as small teardrops or in irregularly shaped fragments varying from the size of a pin head to a hickory nut. It is generally transparent and yellow or reddish in color, although some is opaque and grayish white.

In 1907, Gies' chemical analysis indicated the following percentage elementary composition; C, 78.5; H, 9.5; S, 0.25; O, 11.75. On destructive distillation, succinic acid appeared to be formed and a considerable "quantity of volatile sulphide was evolved." Ash content was only 0.1%.

Because the amber at Kreischerville occurs in close association with leafy twigs of *Sequoia heterophylla* Vel. and *S. Reichenbachi* (Gein.) Heer, Hollick thought that *Sequoia* might also be the source of this amber. He indicates, however, other coniferous remains found in the Kreischerville clay which might have contributed amber: *Widdringtonites Reichii* (EH.) Heer, *Juniperus hynoides* Heer, *Dammara microlepsis* Heer and *Pinus* sp.

Jeffrey and Chrysler (1906) and Jeffrey (1907), on the other hand, studied the lignites from Kreischerville and concluded that *Pityoxylon* (Pinaceous) was the only genus which contained amber. This "pitoxyloid lignite" contained masses of large pieces of amber; smaller fragments were contained in the amber-bearing strata. "The amber enclosed in the lignite appears both in translucent shining condition and in dull ochraceous modification." It not only occurs in "pockets or nuggets but also as fine yellow threads or streaks corresponding to the normal resin passages in the wood."

Thus, only both a possible taxodiaceous and pinaceous source have been suggested for the Kreischerville amber.

Six amber specimens from Kreischerville were run from Harvard Botanical Museum Paleobotanical Collection #52812. All of the spectra were similar to that shown in H 321 (Plate XIV). Thus, the possibility of two sources did not become evident in the particular samples analyzed. The similarity of the spectra from Kreischerville and from the Koalak River in Alaska is noteworthy. Although stratigraphic data for the Kreischerville deposit have not recently been critically assessed, it appears that the amber here is probably only slightly older (Cenomanian) than the Koalak amber (Senonian). Although a taxodiaceous source is strongly indicated for at least part of the amber in both localities, infrared spectra of modern resins of representatives of this family have not as yet provided corroborative evidence. This has been true for the Pinaceae as well.

Magothy River Amber

Troost (1821) described amber associated with lignites at Cape Sable, Magothy River, Anne Arundel County, Maryland. These are the strata which later were designated as the Magothy Formation (Little, 1917). Troost indicated that this amber occurs generally as grains "from the size of a mustard seed to that of pieces from 4 to 5 inches in diameter." Most of it is opaque, varying from brown to yellowish grey; transparent specimens seldom are found. Also some of it is "earthy", occurring as friable, porous masses.

Although Troost was interested in the kind of wood with which the amber was associated, he was unsuccessful in identifying the lignites. Knowlton (1896), however, found at this locality a log which contained small pieces of amber. Poor preservation of wood and its tendency to disintegrate with exposure left its generic determination open to question. Knowlton finally concluded, however, that "as nearly as can be made out, the structure is that of *Sequoia* or *Cupressinoxylon* as the wood is known in the fossil state." He named it *Cupressinoxylon Bibbinsi*, and suggested that this origin was supported by Fontaine's recognition of 15 species of *Sequoia* from similar lignites found elsewhere in the Potomac Group.

Hollick and Jeffrey (1909) concluded that most of the conifers found in Raritan strata, which had previously been referred to Podocarpaceae, Cupressaceae or Taxodiaceae (Sequoiineae), belonged to the Araucariaceae. They recognized, however, the abietinious genera *Prepinus* and *Pinus*. Penny (1947), on the other hand, suggested that some of the Raritan conifers that Hollick and Jeffrey considered aracauriaceous were taxodiaceous. For example, *Sequoia Reichenbachi* (Geinitz) Heer, which is synonymous with *Geinitzia Reichenbachii* (Geinitz) Holl. and Jeff., Penny considers to be essentially the same as *Sequoia ambigua* Heer. He suggests that these species, as well as others of *Geinitzia*, are taxodiaceous rather than araucariaceous. Araucarian remains, nonetheless, are common in the Magothy flora of New Jersey and Delaware.

Five spectra were run of specimens from USNM collection #72871. This amber was generally opaque with some color variation from beige to brown. Four of the spectra gave the pattern shown in H 361 (Plate XVII). Another specimen from this same collection gave the typical Baltic Succinite pattern (Langenheim and Beck, 1965).

A taxodiaceous source is indicated from the wood in which the amber was enclosed, although the identification of this wood is tenuous. The spectral type of this amber (Plate XVIII) forms a family of amber including those from St. George, Delaware (H 357), Bordentown, N.J. (H 225), Cliffwood, N.J. (H 422) and Kincora, N.J. (H 367). This type is more closely related to the type from Manitoba, Canada (Plate XVI), than it is to that from Alaska and Kreischerville (Plates XIV, XV).

Cliffwood Amber

The lignitic sands and clays at Cliffwood Bluff, New Jersey, on Raritan Bay were first included in the Raritan Formation, although they also have been referred to the Matawan Formation (Hollick, 1897; Berry, 1905a). However, the lignites, and amber-bearing beds in particular, were then considered to be in the Magothy Formation. Berry (1905a) states that "a secondary feature of the Magothy Formation is the occurrence of amber, which is found in the form of globular and tear-shaped drops, disseminated in the lignite beds from Cliffwood bluff, in New Jersey, southwesterly to the type amber locality of the coastal plain, at Cape Sable, Md." He indicates further that he has not found amber in pieces "larger than a lima bean, although occasionally one hears from the foreman of the clay pits of much larger masses having been found." Doyle (pers. comm., 1967) confirms the Magothy age of at least some of the Cliffwood lignites on the basis of his palynological studies.

Berry (1905a, b) studied the plant megafossils from Cliffwood and described various coniferous remains. Among the araucarians were *Dammara* and *Araucarites*. Penny (1947) also reported *Araucarioxylon* with tracheal pitting similar to modern species of *Agathis* and *Araucaria* here. Various species of *Pinus*, *Picea* and *Pitoxylon* are reported for the Pinaceae. Holden (1913) also listed *Pityoxylon* from this locality. In the Taxodiaceae, Berry reported various species of *Sequoia*, *Geinitzia* and *Cunninghamites*.

One spectrum (Smithsonian Collection with no number, collected by E.W. Berry from the Cliffwood Brick

Company) H 422 (Plate XVIII) is similar to that of the Magothy River type.

Martha's Vineyard Amber

Amber from Gay Head, Martha's Vineyard, Massachusetts, was collected by Clifford Kay, United States Geological Survey, Boston, Massachusetts. It had been reported previously from this locality by Finch (1824). Only a few small specimens have been found in a dark gray silt rich in fine plant debris, including seeds, cones, needles, leaf fragments and a variety of plant tissue excellently preserved (Kay, pers. comm., 1966). Unfortunately ,these remains have not as yet been identified. Palynological evidence from these beds (J. Doyle, pers. comm., 1967) indicates their belonging to the Upper Raritan or Lower Magothy Formations.

The spectrum (H 111, Plate XXI) is quite distinctive from any of the other ambers from Cretaceous strata. The intensity of absorption in the carbon-oxygen single bond region (8–10μ) may indicate a higher percentage of carbohydrates (as in a gum-resin). The presence of a distinct absorption peak at 11.3μ (885 cm^{-1}) is also notable.

Amber from Other Atlantic Coastal Plain Localities

Amber was obtained from six other localities along the Atlantic Coastal Plain. Stratigraphic data for these localities are unknown to the authors. It is assumed, however, that the amber most likely occurs in Raritan or Magothy beds.

Three spectra of "Ambrosine" from Charleston, South Carolina (USNM collection R7317), were made. The spectral type represented by H 210 (Plate XVII) is typical of that of Baltic Succinite (Beck *et al.*, 1964; 1966; Langenheim and Beck, 1965). Shepard (1870) suggested that this amber originated from conifers from the "pleiocene epoch." Stratigraphic data are lacking, but Ambrosine has generally been considered from Cretaceous Atlantic Coastal Plain deposits (probably from the Tuscaloosa Formation, which does not differ greatly in age from the Magothy, according to Groot, Penny and Groot (1961)). Shepard described the original collection as an irregular, oval-shaped mass the size of a man's fist, yellow-brown externally but clove-brown inside. It melted to a clear yellow liquid at 460° F, giving considerable succinic acid before melting. On fusion, a dense yellow oil was volatilized, producing an odor similar to the resin of pines. It was largely soluble in turpentine, alcohol, ether and chloroform. The name "Ambrosine" was coined by compounding the two words "amber" and "rosin."

Three spectra were run from Kincora, Burlington County, New Jersey, from the United States National Museum Collection 5610. Spectrum H 367 (Plate XVII) is similar to that typical of the Magothy River family of ambers. A variation of this spectrum with a band developed at 12–12.3μ (833–813 cm^{-1}) also occurs.

A single spectrum was made of amber from St. Georges, Delaware (USNM #82552). Spectrum H 357 (Plate XVIII) is generally similar to those from the Magothy River and Kincora, New Jersey, localities (Plate XVII). Three spectra were made of amber from Bordentown, N.J., (USGS collection #95367). All three were similar to that represented by H 225 (Plate XVIII), although the 9.8μ (1020 cm^{-1}) band is sometimes more accentuated. This spectral type also belongs to the Magothy River family.

Eleven spectra were made of amber from USNM collection R 7289 from Roebling, N.J. Considerable variation in spectra occurs from specimens in this single collection. The general variation is shown in spectra H

350, H 416, and H 420 (Plate XIX). All of this amber is opaque, with the color varying from light beige to streaks of almost black. The variation in the spectra appear to be due largely to intensity and resolution of the bands. Roebling Type I resembles the Magothy River family of spectra.

Amber from Harrisonville, N.J. (Gloucester Co.) was reported by Kunz (1883). It was found from 20 to 28 feet under a green sand or marl containing invertebrate fossils which were considered "to belong to the middle bed of the Upper Cretaceous series." Kunz indicated that no analysis had been made of this amber, but he felt "the similarity in specific gravity, hardness and ignition leaves little doubt of its being true amber, or of its having been derived from a gum closely resembling that which is the source of the Baltic and other ambers."

The spectrum H 409 (Plate XX) disproves this relationship completely. The Harrisonville amber differs from almost all other fossil resins in that it lacks a well defined carbonyl group. Carbon-carbon unsaturation causes a sharp absorption band at 6.1μ (1650 cm^{-1}) of such intensity that the broader hydroxyl absorption in this region fails to obscure it. The distinctive pair of bands at 13.3μ and 14.3μ (750 cm^{-1} and 700 cm^{-1}) is clear evidence for the presence of mono-substituted benzenoid rings. This indicates a composition similar to that of the European fossil resin siegburgite which has been related to *Liquidambar* by chemical studies in which cinnamic acid and styrene were isolated (Klinger and Pitschki, 1884). These aromatic resins form a small but distinctive family of their own, which differ dramatically from the usual terpenoid resins which alone can be called "true amber."

The resin from Pemberton, N.J. (H 417, Plate XX) is of the same aromatic type as the Harrisonville sample with the exception of lacking the broad intense band which obscures the region between 8 and 11μ (1250 and 990 cm^{-1}) in the Harrisonville sample. It also may well be due to inorganic impurities (silicates) which are characteristic of the European siegburgite.

Canadian Amber

Tyrrell (1890) investigated the occurrence of amber associated with fragments of decayed wood on the beach around the southwestern margin of Cedar Lake, near the mouth of the Saskatchewan River, Manitoba, Canada. He reported abundant amber along the beach for a mile, in a band thirty feet wide with a minimum depth of two feet. He further estimated that this deposit contained 1,437,280 (!) pounds of amber. He also discovered amber occurring less extensively on shores of other lakes north and east of Cedar Lake. Because the amber has been deposited secondarily, the geologic age is uncertain. As Carpenter *et al.* (1938) indicated, however, Cedar Lake is fed by an easterly flowing river that drains through lignitic beds of late Cretaceous age in Alberta and south Saskatchewan. Thus, other amber-bearing deposits from which Cedar Lake amber could have originated are not evident. Carpenter *et al.* point out that the insect inclusions also provide support for a Cretaceous age. Evidence for a more specific time during the long Cretaceous interval, however, is not available.

Although it cannot be definitely related to the Cedar Lake deposits, amber with insects found recently at Medicine Hat, Alberta (Richards, 1966), is of some interest in regard to the Manitoban material. The Medicine Hat amber is associated with lignitic deposits from the Foremost Formation (Belly River Series, Upper Cretaceous). The Belly River Series falls within the Campanian Stage, as K/Ar dates for the Bearpaw shales that occur immediately above the Foremost horizons at Medicine Hat range from 72 to 73 million years. None of this amber has as yet been available for analysis.

Amber collected by Tyrrell was studied by Harrington (1891) and named chemawinite. Klebs (1896), apparently unaware that Harrington had described it, analyzed the same type of amber from Cedar Lake and called it cedarite. Schmid (1930), in his review of fossil resins, classifies them as (a) "*Bernstein* which yields succinic acid on distillation, the principal type being succinite, (b) those resembling *Bernstein*, including cedarite, and (c) those quite different from (*fern stehende*) *Bernstein*, including chemawinite." Walker has already pointed out, "the two Canadian minerals, cedarite and chemawinite, are identical, as appears probable both from the chemical and physical data recorded by Harrington and Klebs, and from the localities from which the material was obtained." Harrington (1891) made the most complete chemical analysis of this amber. The hardness was 2.5; the specific gravity 1.055 at 20° C. The mean percentages of constituents from elemental analyses were: C, 79.96%; H, 10.46%; O, 9.49% and ash 0.9%. The ash contained silica, alumina, iron, calcium and magnesium. 20.01% of the amber dissolved in absolute alcohol and 24.84% in absolute ether. Small fragments heated in a closed tube began to soften at about 150° C. Heated to 300° C, the resin did not melt into a flowing liquid but had become soft and elastic and darkened from partial decomposition. Harrington concluded that this Canadian amber was more resistant to heat than Baltic amber. Succinic acid, so characteristic of Baltic amber (Succinite), is absent. These facts, in addition to the presence of more carbon and less oxygen than Baltic Succinite, led him to conclude that the Canadian amber "is closer to Walchowite and to some of the more recent copals from India."

This Canadian amber is transparent, varying from pale yellow, red to dark amber in color. Walker (1934) reported that the smallness of the amber grains (58% being less than eight mesh and only 3% larger than two mesh) was a point of difference from that of the generally larger masses characteristic of Baltic amber. He suggested that this might indicate conifers of types yielding little resin when wounded, in contrast to those which produced resin copiously in the Baltic forests.

Eleven spectra were run on amber from Cedar Lake. Ten of these spectra were of specimens from the Harvard University Entomological Collections. All of these gave the same pattern represented by H 316 (Plate XVI), although some spectra were sharper than others. Also the pattern of amber from Cedar Lake, Manitoba, is similar to Ambrite (H 226, Plate XVI) from New Zealand (USNM #7312). Both of these spectra, in turn, are similar to resin from *Agathis australis*, the Kauri pine (H 265, Plate XVI). Since *A. australis* is noted for its capacity to produce large quantities of resin, it is a logical source for fossilized resin from New Zealand. A possible Araucarian source, such as *Agathis* or related araucarians, for this Canadian amber is interesting and suggestive. More resins of members of the Araucariaceae need to be analyzed, before a definite correlation is made. Also the possible presence of *Agathis australis* (called *Dammura australis* Lamb.) in the Kreischerville, N.Y., deposits is noteworthy. Certainly, in the Potomac (Albian), Raritan (Cenomanian-Turonian) and Magothy (Early Cenomanian) Formations along the Atlantic Coastal Plain, members of the Araucariaceae were common, and an araucarian-type resin could well be expected. Araucarian leaf remains, i.e., *Araucarites longifolia*, are reported from Upper Cretaceous beds in the Rocky Mountains (Lance) by Dorf (1942), although remains similar to *Agathis* have not been listed.

One Cedar Lake specimen (USNM #97080) gave a spectrum similar to that of Baltic Succinite (Langenheim and Beck, 1965). The presence of this spectral type might suggest two different botanical sources of the amber from the Manitoban deposit.

Baja California Amber

Buddhue (1935) described "Bacalite" as amber presumably from Baja California, Mexico. Since this amber cannot be shown to have come from Baja California, Langenheim, Buddhue and Jalinek (1965) recognized that "it may have come from any place in the world." They mention, however, the particular likelihood of its being from the amber deposits of Chiapas, Mexico.

Hurd, Smith and Durham (1962) reported documented occurrences of amber from Baja California, based on the discovery by A.C. Allison and F.H. Kelmer. Langenheim, Buddhue and Jelinek (1965) further elaborated on the age and occurrence of this amber. It has been observed at three localities between Punta San José and Punta Cabras. At each locality, a single nodule of amber from $1\frac{1}{2}$–2 inches in diameter was collected from siltstone or sandstone thought to be latest Campanian or earliest Maestrichtian in age. At Punta Baja, about 10 miles southwest of El Rosario, small fragments of amber occur in sandstone with carbonized leaf impressions. *Metaplefenticiras pacificum* Smith occurs in the same bed and indicates late Campanian age. Small grains of amber and carbonized wood were also reported from a sandstone interbedded with a claystone south of the mouth of Arroyo Rosario.

Four spectra were run from a single collection (University of California, Museum of Paleontology, B–3006) from the Punta San José locality. The material generally is opaque, varying in color from beige to molasses to almost black. More variation occurred in the spectra from these few pieces than is frequently the case where a larger number of samples have been run, i.e., from Chiapas, Mexico and Alaska. Three spectra showing this variation are presented in Plate XXII. Type I (H 45) and Type II (H 320) are similar, but Type III differs in having a broader and more intense absorption band between 9–10μ (1110–1000 cm^{-1}). This may be due to inclusions of siliceous material. Type III was taken from a light beige portion of a banded specimen of which Type II represents the darker portions. As indicated with the Roebling, N.J. amber, more heterogeneity must be expected in the opaque amber types than in the transparent ones.

EARLY TERTIARY AMBER

Amber is reported to occur in strata from early Tertiary time(Eocene to Miocene)in various areas throughout North and South America. A fairly extensive deposit has been discovered in Chiapas, Mexico, and is being intensively investigated by geologists, entomologists and botanists. Thus, the Chiapas deposit can serve as a useful standard for comparison of other Tertiary ambers as the Alaskan deposit does for Cretaceous ambers. Small amounts of Eo-Oligocene amber occur near Seattle, Washington; amber of probable Oligocene age occurs in the Dominican Republic and of Miocene age in Pará, Brazil. The age of amber from several other localities probably is early Tertiary, but stratigraphic data are lacking.

Chiapas Amber

Amber from Chiapas, the southernmost state in Mexico, has been reported in mineralogical studies (Helm, 1891; Kunz, 1903; Tschirch, 1906; Hintze, 1933;

Buddhue, 1935; Tschirch and Stock, 1936), but it has neither been analyzed chemically and physically nor been given a mineralogical name. The geologic occurrence was first recorded by Böse in 1905. A coordinated scientific investigation was initiated by entomologists and later included geologists and botanists (Hurd and Smith, 1957; Hurd, Smith and Durham, 1962; Langenheim, 1964, 1966, 1967; Langenheim, Hackner, and Bartlett, 1967).

The amber-bearing beds are in a sequence of primarily marine, calcareous sandstones and siltstones which are mostly exposed in landslides. All amber-bearing localities are considered latest Oligocene to earliest Miocene in age, based on marine invertebrate fossils (Licari, 1960; Hurd, Smith and Durham, 1962). Pollen from the strata either containing the amber or immediately adjacent to them indicates development of mangrove vegetation of considerable complexity at or close to the site of deposition of the amber (Langenheim, Hackner and Bartlett, 1967).

Previous discussions have presented evidence supporting the conclusion that this amber was derived from the leguminous genus *Hymenaea* (Langenheim, 1963; Langenheim and Beck, 1965; Langenheim, 1966; and Langenheim, 1967). Spectra were made of various resins from populations existing in Chiapas today. Each genus, as well as certain species populations, was clearly distinghishable. Remarkably consistent spectra were obtained from 35 samples of *Hymenaea Courbaril* L. from various populations in Mexico, Guatemala, Dominica, Costa Rica, Guyana, Venezuela, Brazil and Ecuador. Forty specimens of Chiapas amber from the University of California, Museum of Paleontology Collections from various localities were chosen for spectra because they showed some difference in physical character. The color of this amber varies from yellow, golden brown, red to black; the most common being the yellow and golden brown hues. Variety in appearance tended to indicate that several kinds of trees might have produced the amber. All but two specimens fit into two spectral patterns indicated as Type I (H 1A) and Type II (H 88), Plate XXIII. A third type (H 1C) gives an ill defined spectrum. It was, therefore, initially assumed that these three patterns might indicate three different sources (Langenheim, 1963). The two major types (14 samples of each), however, are similar to each other, except for the more general flattening of the bands and loss of the sharp band at 11.2–11.3μ (895–885 cm^{-1}) in Type II. The similarity is now thought to be sufficient to suggest that both Type I and Type II were derived from the same source and that the differences may be explained by additional atmospheric oxidation and progressive polymerization. The two specimens representing Type III (H 1C, Plate XXIII) are black in general appearance, although small pieces show a ruby red color in transmitted light. The pieces are extremely soft and friable, indicating that they had been partially decomposed. Type I had a spectrum similar to that of *Hymenaea Courbaril* (H 1B-IV, H 58, Plate XXVII), although there are some differences. Langenheim and Beck (1965) explained that the broad band at 14.2–14.4μ (705–700 cm^{-1}) due to unassigned skeletal vibration has disappeared in the amber. The 11.3μ (885 cm^{-1}) band which can be assigned to $=CH_2$ out-of-plane deformation of terminal carbon-carbon bonds decreases, as would be an expected result of progressive oxidation by atmospheric oxygen. The attendant formation of new carbon-oxygen bonds would also account for the slight shift of absorption maximum near 8μ (1250 cm^{-1}) which is more often at 7.6μ (1295 cm^{-1}) in the *Hymenaea* resin but more often at 8.1μ (1235 cm^{-1})

in the amber. It is also significant that none of the other resin producers in Chiapas today had spectra resembling the amber (Langenheim and Beck, 1965). Thus, the infrared spectra have given convincing evidence that the Chiapas amber was derived from an ancestral member of ***Hymenaea.***

The presence of ***Hymenaea*** leaflets in the amber provides further corroboration for the source (Langenheim, 1966). This conclusion receives additional support from studies of the manner of resin production and accumulation in ***Hymenaea** Courbaril* (Langenheim, 1967) and the depositional conditions of the amber. ***H.** Courbaril* produces large quantities of resin that accumulate in the soil around the roots, and in Mexico today it grows commonly along rivers that enter the ocean in mangrove-fringed estuaries. Analysis of the pollen in the amber-bearing beds indicates that the amber was deposited in such an estuarine environment with abundant mangrove present (Langenheim, Hackner and Bartlett, 1967).

Seattle Amber

Amber from the Renton Formation near Seattle, Washington, was discovered by J. Wolfe. Vine (1962) considers the Renton to be late Eocene to early Oligocene in age. Wolfe (pers. com., 1966) reports that there are no plant fossils at the amber locality itself, although they are common in the Puget Group, of which the Renton Formation is a member. Conifers present are taxodiaceous, including *Sequoia*, *Metasequoia* and *Glyptostrobus*. The dicotyledenous flora is rich but still largely unidentified. The La Porte and Comstock floras are about the same age as the Renton.

Five spectra were run of amber from the Museum of Paleontology, University of California Collection B8427. Most of this amber occurs in small friable pieces. It is pale yellow and transparent. Chemical and physical analyses have not been made. There was some variation in the spectral patterns (Plate XXIV) as indicated in Type I and Type II (Spectra H 323 and H 42A). These spectral types from Seattle are similar to those of Types I and II from Baja California (Plates XXII and XXIV) which indicates possibly that they may be from the same source. There are no present suggestions for the botanic source from these two localities either from associated plant remains or from spectra of modern resins.

Dominican Republic Amber

Sanderson and Farr (1960) state that amber was first reported from what now is the Dominican Republic by Christopher Columbus during his second voyage to the West Indies between 1494 and 1496. No further reference to Dominican amber during the next 400 years appears to have been recorded. In 1905, Sample described an amber-bearing formation in the Monte Cristi Range (Cordillera Septentrional). Lengweiler (1939) then reported that fragments of lignite, leaves, and insects, such as mosquitos and ants, were found in the amber.

Sanderson and Farr (1960) indicate that the amber-bearing formation in the Dominican Republic are located at two principal sites in the Cordillera Septentrional north of Santiago between Altamira and Conca. The original site is the Pena (Tamboril) region in the two gorges of the Arroyo Capancho tributary of the Rio Gurado. The second site is below Pico Diego de Ocampo in the Palo Alto de la Cumbre region. Sanderson and Farr collected the amber in a light brown-dark grey, fine-grained, micaceous sandstone occurring below a silty shale at this second site. Brower (Sanderson and Farr, 1960) believes this amber to be Oligocene in age, although the exact date remains in doubt. The amber occurs irregularly as small broken fragments to large unbroken pieces. Transparent, unfractured pieces are common, but many small broken pieces are brittle and fracture. The color varies from clear crystal through various amber-shades to deep red. Chemical or physical analyses have not been made of this amber.

Six spectra were made of amber from the Dominican Republic. Type I (H 37) is from a specimen from the Palo Alto de la Cumbre site collected by Sanderson (Plate XXV). Three others from an unidentified locality near Santiago gave a pattern similar to this one from the known site. Two were run of specimens from USNM collection #R6783, from Palo Quemado, Santiago Province, Santo Domingo. These samples gave a more generalized spectrum as represented by (H 427) than the other four (Plate XXV). They are designated as spectral Type II, and represent probably more oxidized specimens as indicated by the almost complete loss of the 11.3μ ($885\ cm^{-1}$) band. The spectral pattern is unique for North and South American ambers examined thus far. No extant groups have given a pattern similar to this, and, with correlative paleobotanical data lacking, there presently is no hint as to botanical source.

Brazilian Amber

A single piece of amber has been collected from the Pirabas Formation near Capanêma, Pará, Brazil. This formation is considered early Miocene in age and is accompanied by numerous dicotyledenous leaves (Lelia Duarte, pers. com., 1966). Spectrum H 452 is closely similar to resin from extant *Hymenaea Courbaril* (Plate XXVIII), especially from Brazil (H 61) and Costa Rica (H 252). *Hymenaea* thus appears to have been the source of this amber as well as that from Chiapas, Mexico. Perhaps future paleobotanical studies on these beds will give additional supporting evidence.

AMBER OF UNKNOWN AGE

The geologic age and paleobotanic information are not available for a number of amber collections. These collections are being presented separately, although they will be related to ambers of known age wherever this appears justifiable.

Greenland Amber

Two spectra were made of amber from Hare Island in Greenland from a collection from Museum für Naturkunde, Berlin. The amber occurred as droplets in coal. The spectrum (H 165) is poorly developed, due probably to oxidation (Plate XV). This amber is assumed to be Cretaceous, because of the extensive, well known Cretaceous plant fossil localities in this area of Greenland, although there is no direct confirmation of this age.

Montana Amber

Nine spectra were run of the amber from Montana. Collections were available from the United States National Museum and the New York Museum of Natural History. No geologic age is indicated for this amber. Four spectra were made from the USNM Collection #112822, listed only from "Montana." They are represented by the Type I pattern represented by H 404 (Plate XX). This is the third example of the aromatic series described above from Pemberton, N.J. (H 417) and Harrisonville, N.J. (H 409). The Montana sample is virtually indistinguishable from that from Pemberton. Both lack the broad absorption band of the Harrisonville sample between 9 and 10μ (1110–1000 cm^{-1}) which we have assigned to silicate impurities.

Five spectra were run from the N.Y. Museum of Natural History collection #18395, listed from Washoe, Montana. Four spectra gave the pattern of Type II

(H 405) and one gives Type III (H 425) shown in Plate XXI. The small differences between these two types may be due to oxidation and progressive polymerization. Both are similar to the Magothy River family.

Cañon Diablo, Arizona Amber

One spectrum (H 365) of amber was run from USNM collection #62993 (Plate XXIV). The age of this sample is unknown; in fact, no data are available for it. The spectrum is somewhat like those belonging to the Atlantic Coastal Plain Magothy family of ambers.

Ecuadorian Amber

Amber from a "large deposit" near Guayaquil, Ecuador, was reported by Johnston (1838) and named Guayaquillite. No geologic age was given. Two kinds, a light yellow, almost homogeneous material and a dark brown, bituminous-like substance, were found. The "pure" mineral is opaque, powders easily, and is soluble in alcohol. The specific gravity is 1.092 and the melting point between 157°–212° C.

Three spectra were made from USNM collection #R7328. Spectrum (H 212) is typical for the three (Plate XXV). Frondell (1967) has shown that X-ray diffraction patterns of Guayaquillite are similar to those of a sample of various species of *Protium*, a genus in the Burseraceae. Some infrared spectra of *Protium Icicariba* suggest the same relationship, whereas other species of *Protium* differ significantly.

Colombian Amber

We have examined amber from two localities in Colombia. Boussingault (1843) reported amber to have been found in large amounts in a gold-bearing alluvium at Girón, near Bucaramanga, Departamento de Santander del Norte. From the locality, this amber has been named Bucaramangite. Since it was found in alluvium, it might have been transported some distance from beds of any age. The sample analyzed came from a pale yellow transparent piece that weighed 12 kg. It is insoluble in alcohol, swells and becomes opaque in ether and does not contain succinic acid.

Four spectra were run from USNM collection #R7317. Three spectra (Plate XXVI) were similar to Type I (H 429). Another spectrum was like Type II (H 208) which had a better resolved version of Type I.

Cockerell (1923) reports two species of *Diptera* in amber from the Valle de Jesús in the Departamento de Santander del Sur. He characterized it only as being "relatively soft" and of "uncertain age."

Amber from Medellín, Colombia, is also available from USNM collection #97466. Although it is listed as "copalite," we are unaware that its geologic age or its chemical or physical description have been published. Six spectra were run and H 359 (Plate XXVI) is representative of them.

The spectra represented by H 208 (Girón) and H 359 (Medellín) can be related generally to spectra of *Hymenaea Courbaril,* just as in the case of amber from Chiapas, Mexico. In previous discussions of Chiapas amber (Langenheim and Beck, 1965; Langenheim, 1966; Langenheim, 1967), spectra of resin from modern populations of *Hymenaea Courbaril* were compared from Mexico, Guatemala, British Guiana (Guyana), Brazil, Venezuela, and Ecuador. Considerable similarity in the spectra throughout the wide distribution of this population was noted, although certain populations were more similar than others. For example, spectra of the Chiapas amber resembled more closely the spectra of *Hymenaea* resin from populations in Mexico and Guatemala than those with a more southern distribution. Therefore, it was not surprising when the spectra of amber from Girón and Medellín, Colombia, compared closely with *H. Courbaril* resin from Guyana and Brazil (Plate XXVII). We presently do not have specimens of *H. Courbaril* from Colombia.

These spectra of Colombian amber seem sufficiently close to present-day *Hymenaea* to indicate its possible botanic origin. Unfortunately, we do not know the geologic age nor have corroborative evidence for the botanic source from plants included in the amber or in the amber-bearing beds, such as was available for the amber from Chiapas, Mexico.

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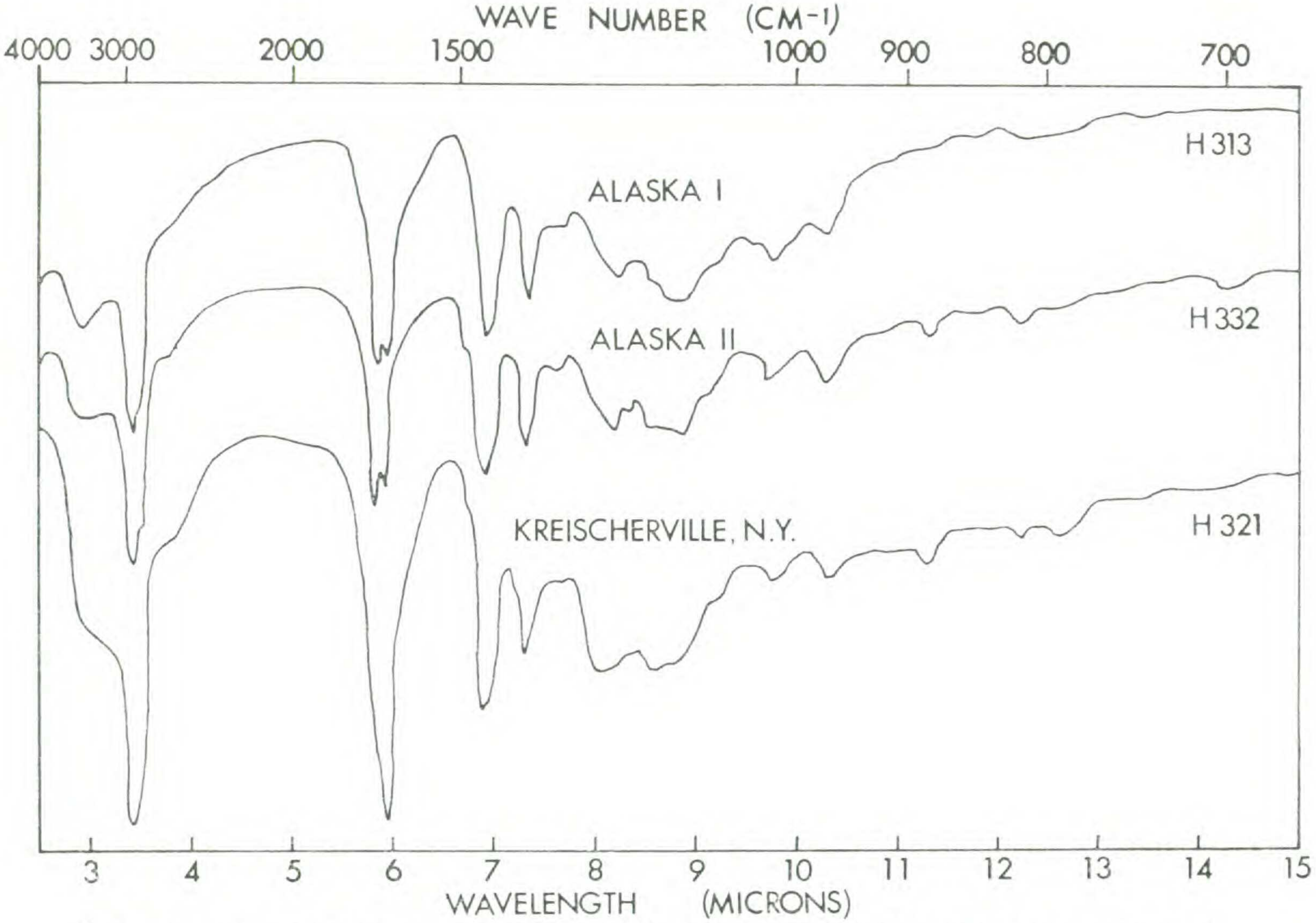
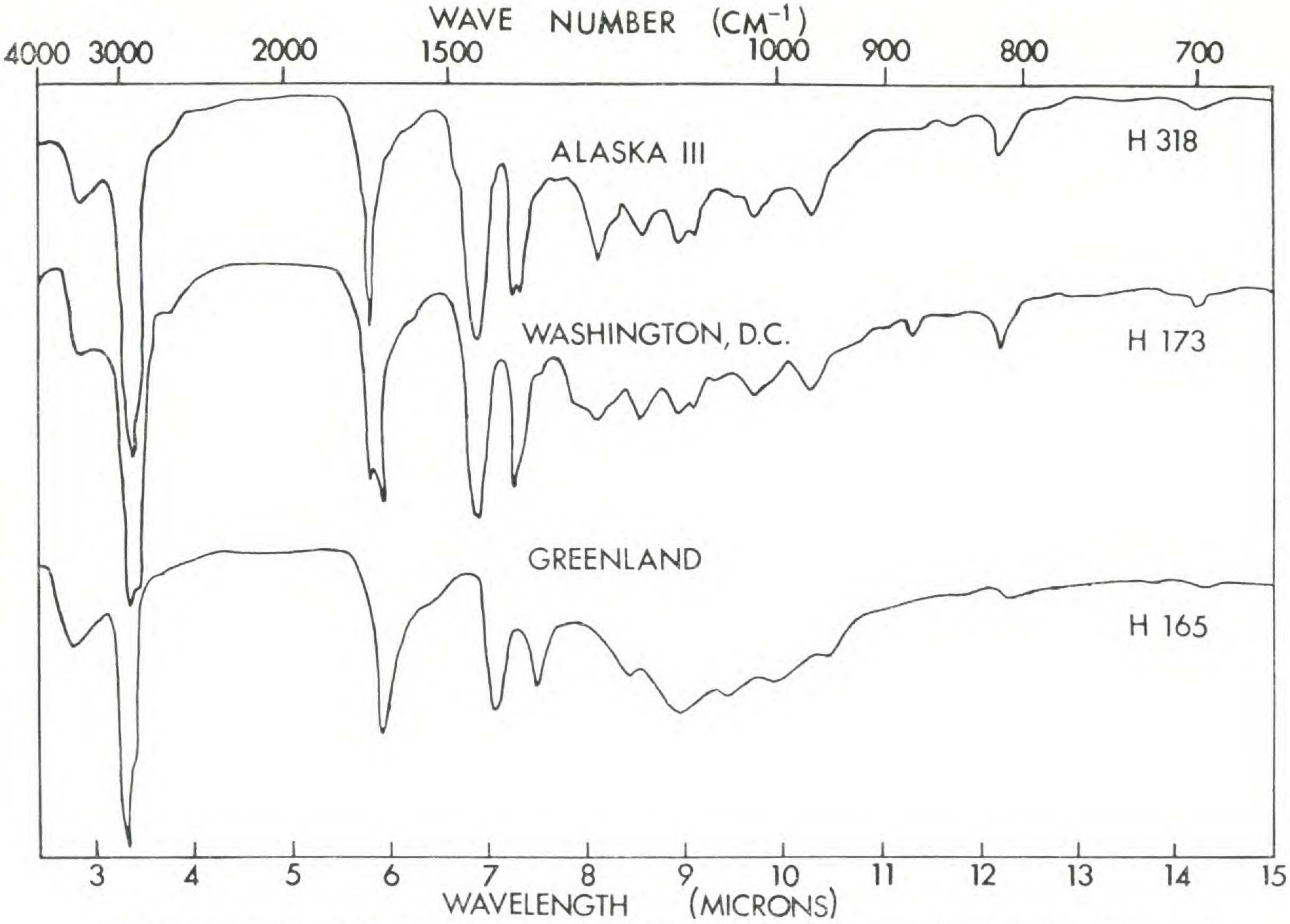
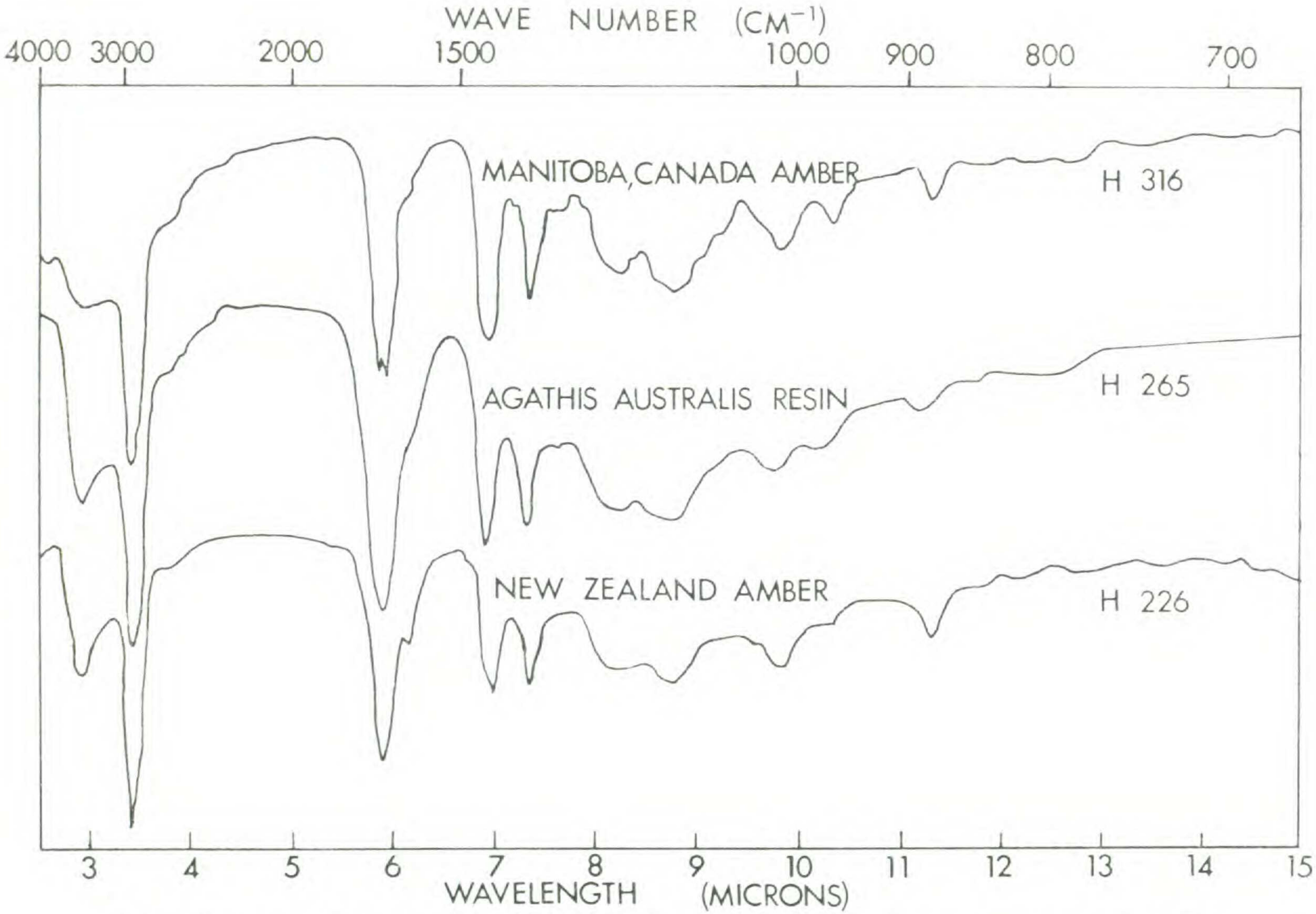


Infrared spectra of Cretaceous amber from Alaska Types I and II and Kreischerville, N.Y.

PLATE XV

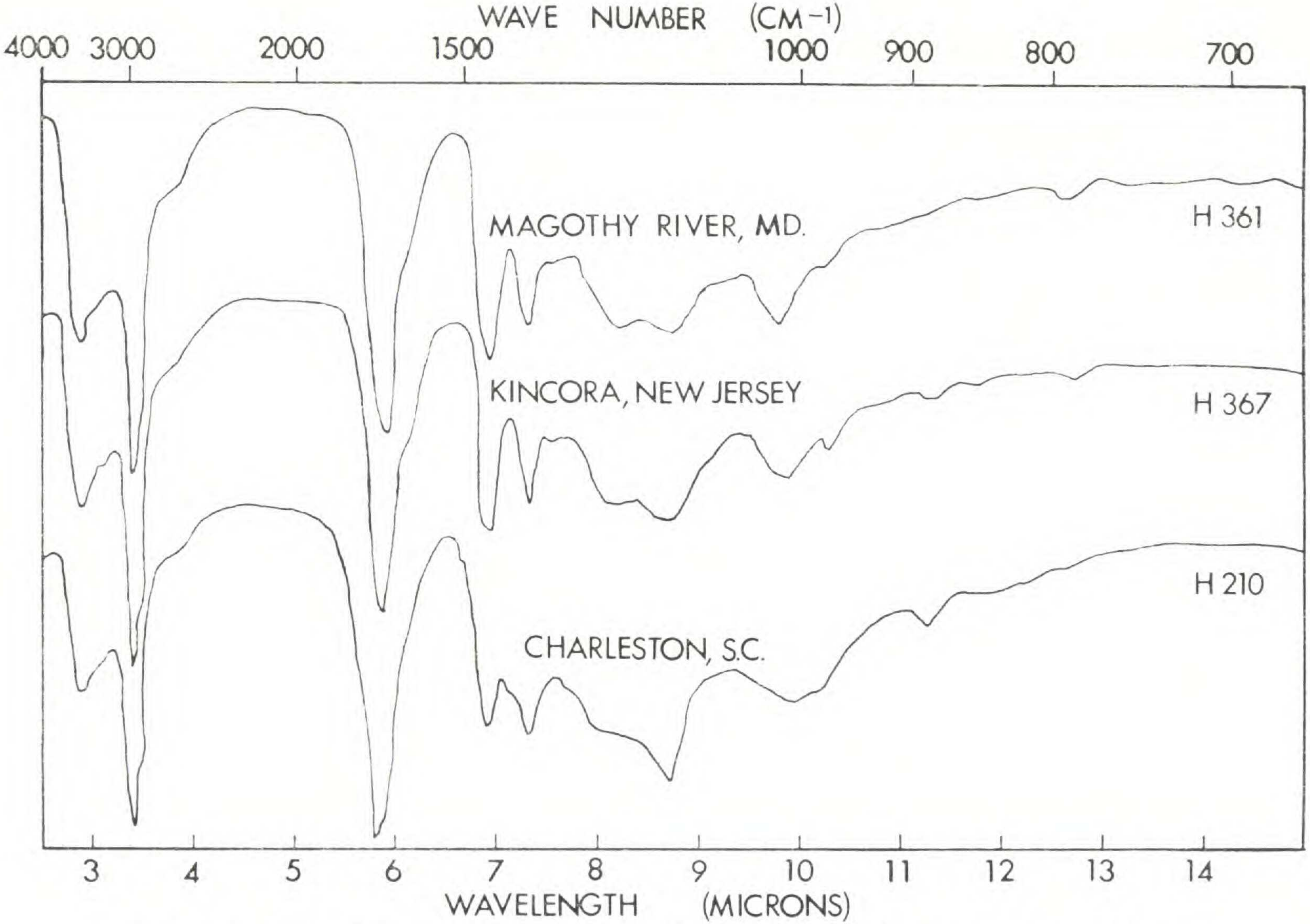


Infrared spectra of Cretaceous amber from Alaska Type III, from Washington, D.C. and of unknown age from Greenland.



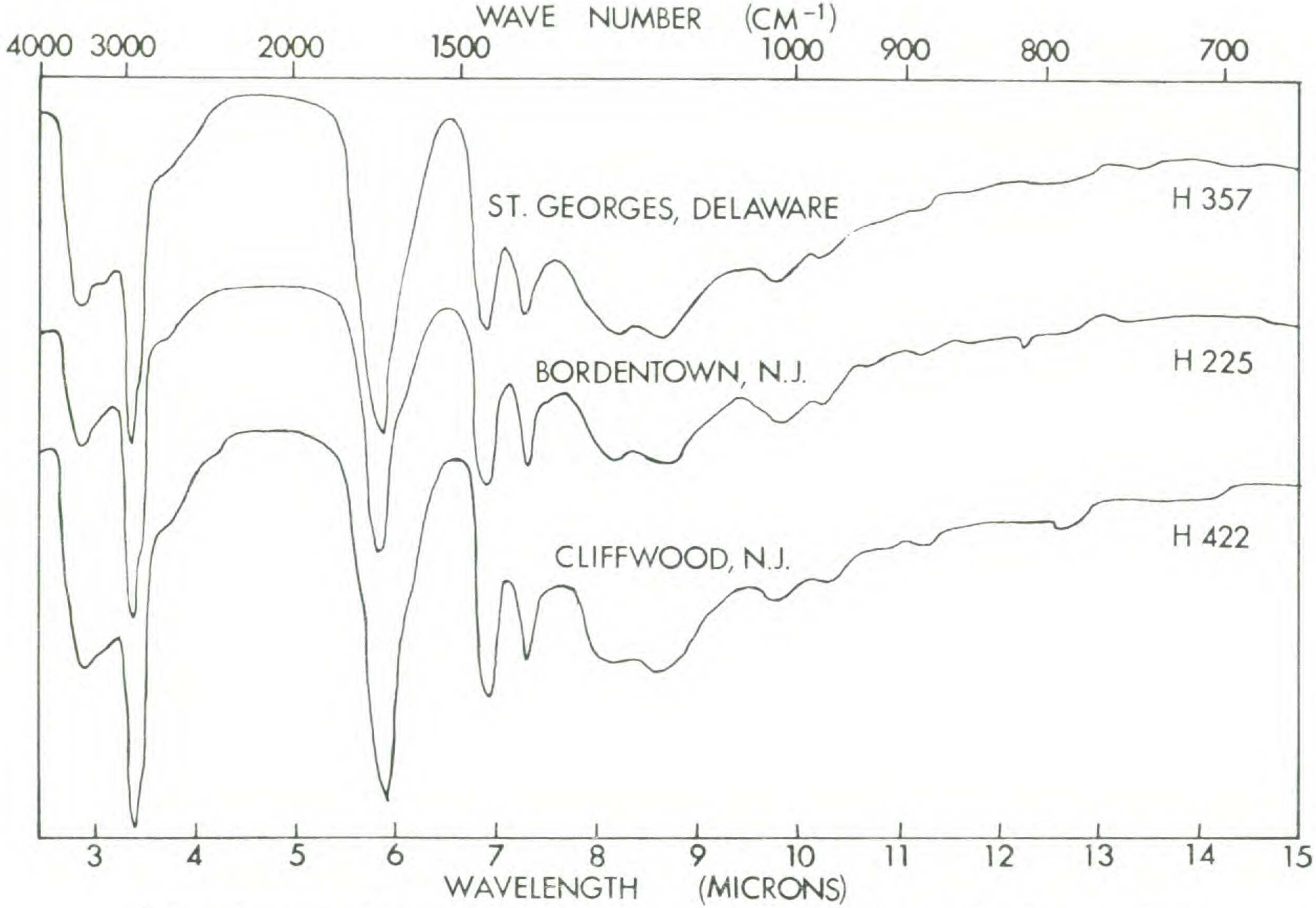
Infrared spectra of Cretaceous amber from Manitoba, Canada, Pleistocene amber from New Zealand, and of modern resin from *Agathis australis*.

PLATE XVII



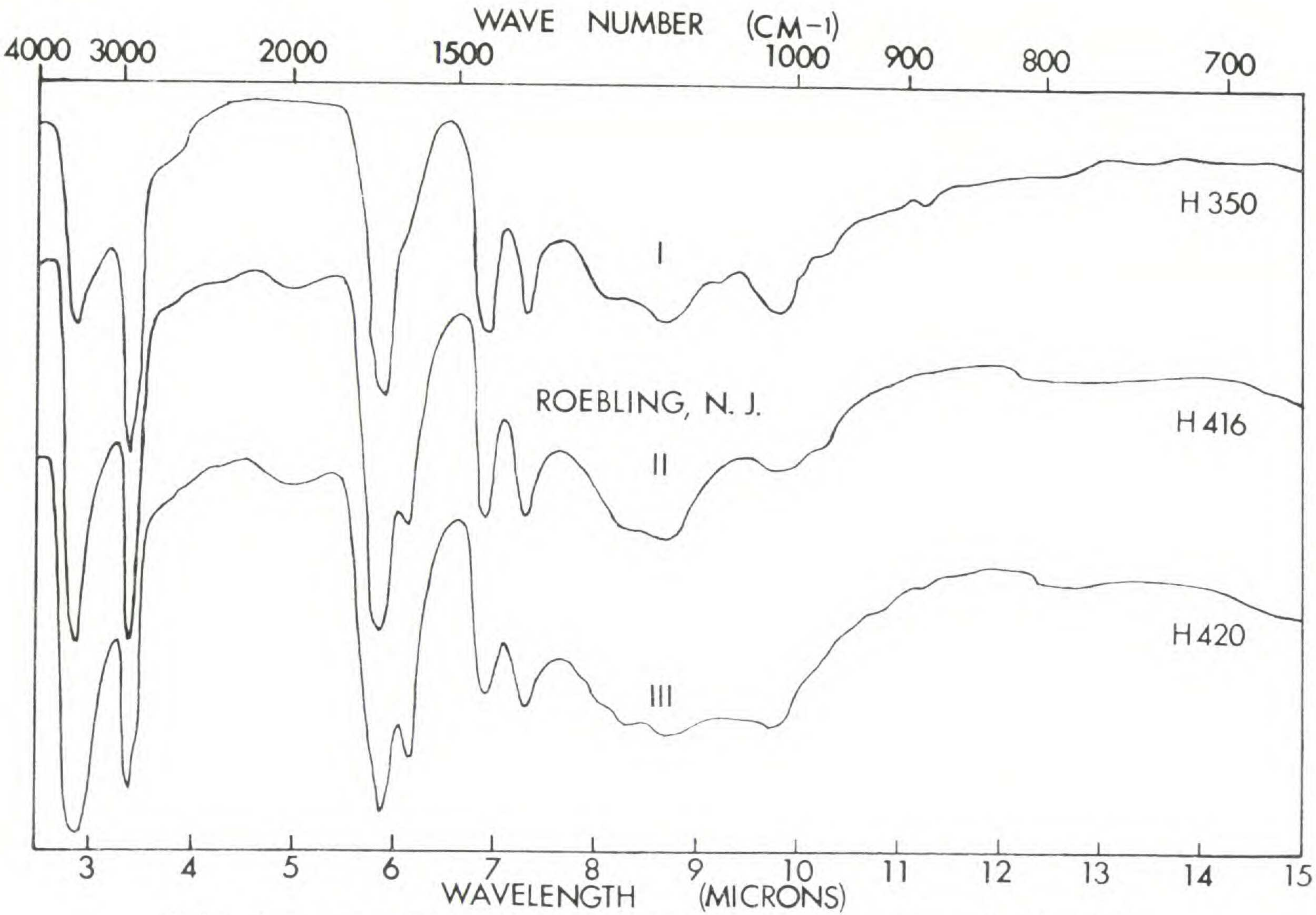
Infrared spectra of Cretaceous amber from Magothy River, Maryland; Kincora, N.J.; and Charleston, S.C.

PLATE XVIII

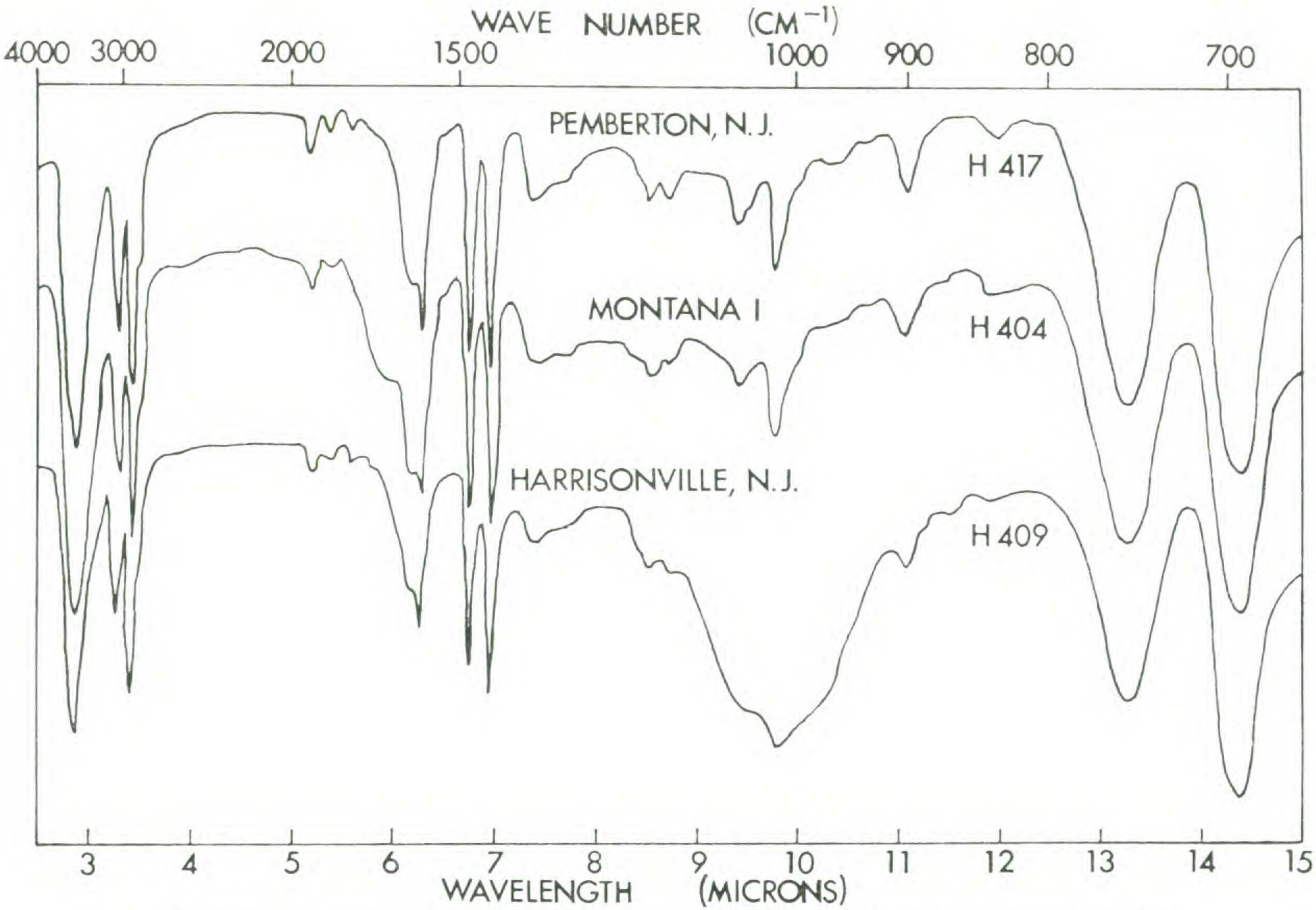


Infrared spectra of Cretaceous amber from St. Georges, Delaware; Bordentown, N.J.; and Cliffwood, N.J.

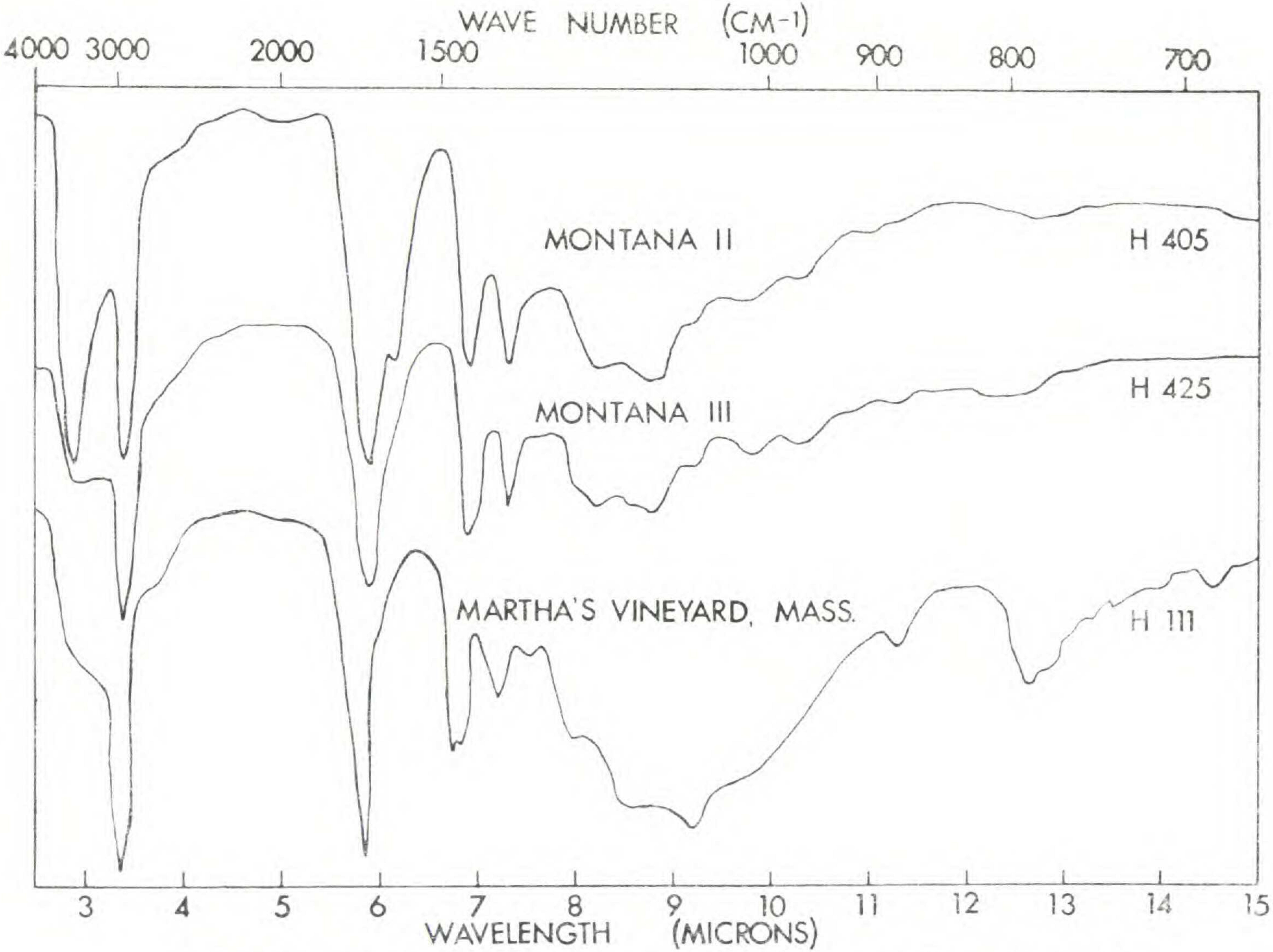
PLATE XIX



Infrared spectra or Cretaceous amber from Roebling, N.J. Types I, II and III.

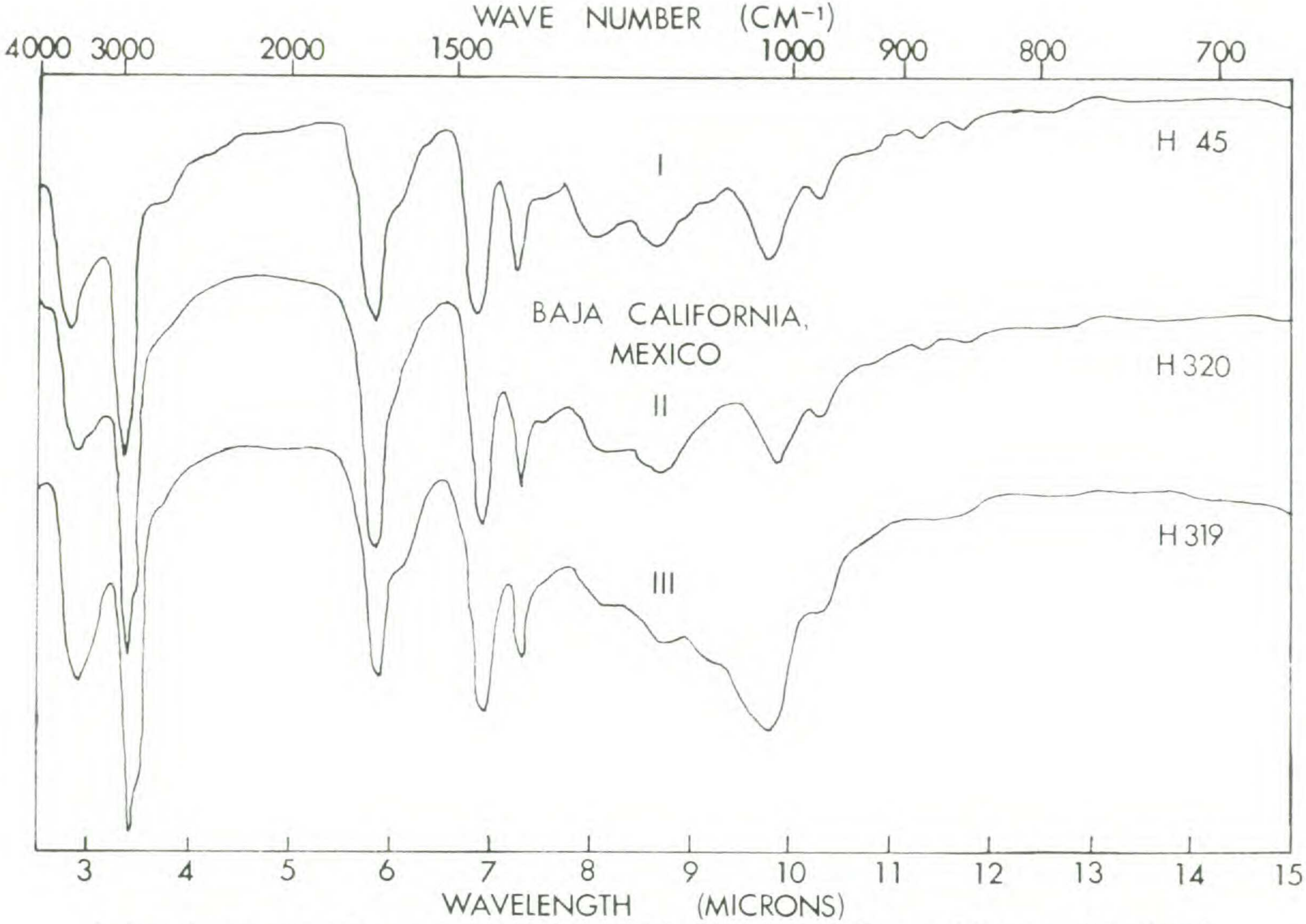


Infrared spectra of Cretaceous amber from Pemberton, N.J. and Harrisonville, N.J. and unknown age from Montana Type I.



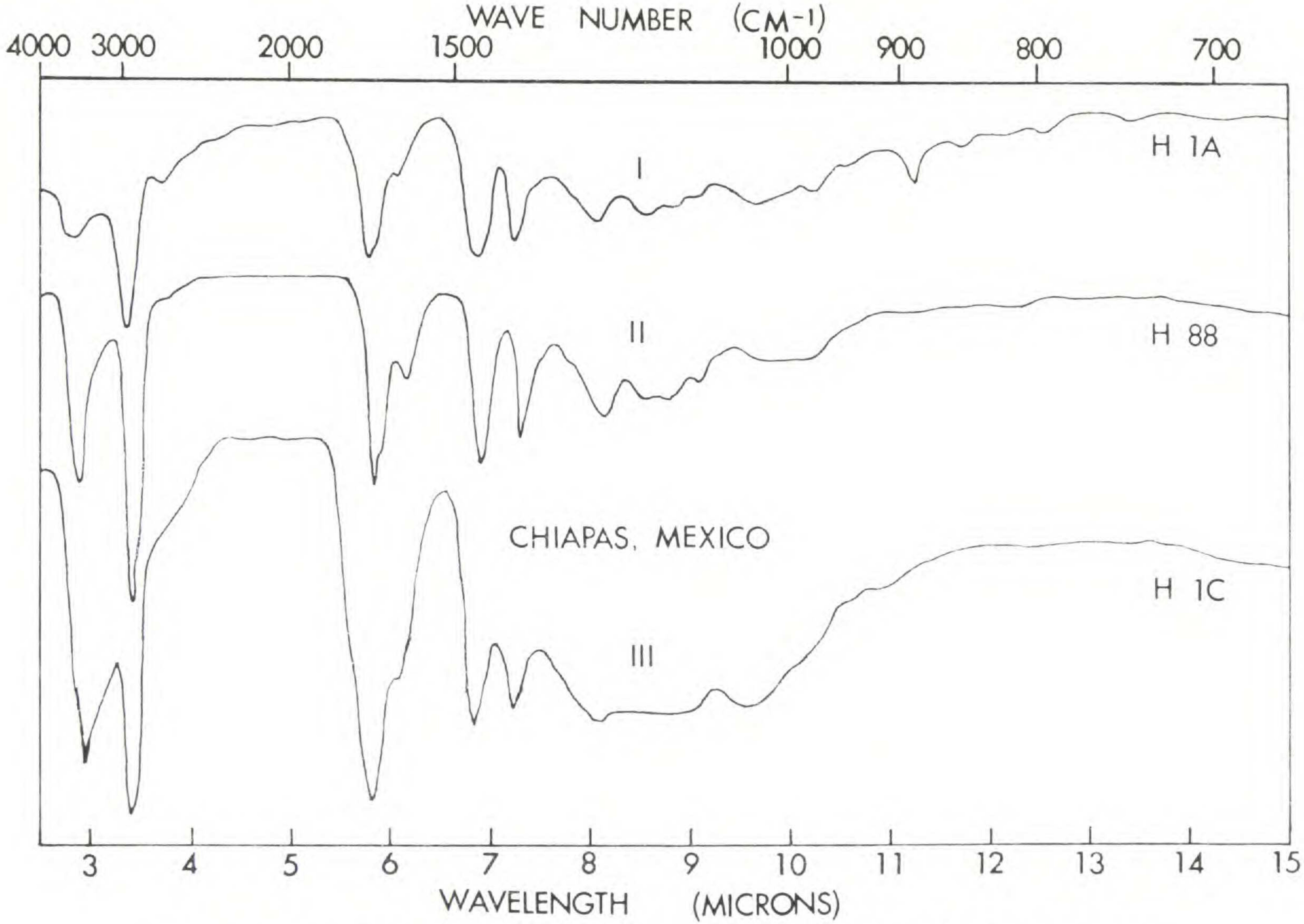
Infrared spectra of amber of unknown age from Montana Types II and III and Cretaceous amber from Martha's Vineyard, Mass.

PLATE XXII



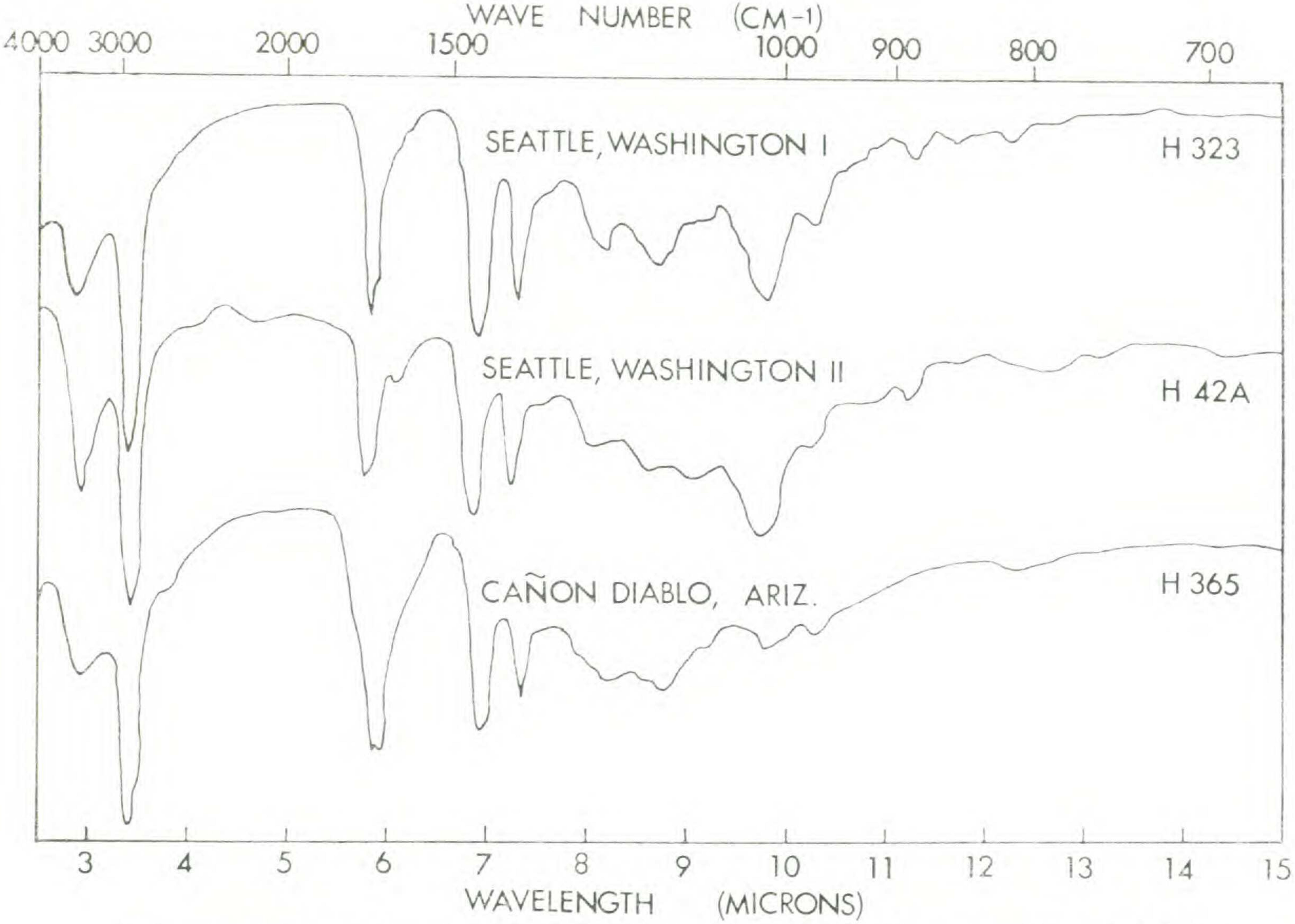
Infrared spectra of Cretaceous amber from Baja, California, Mexico, Types I, II and III.

PLATE XXIII



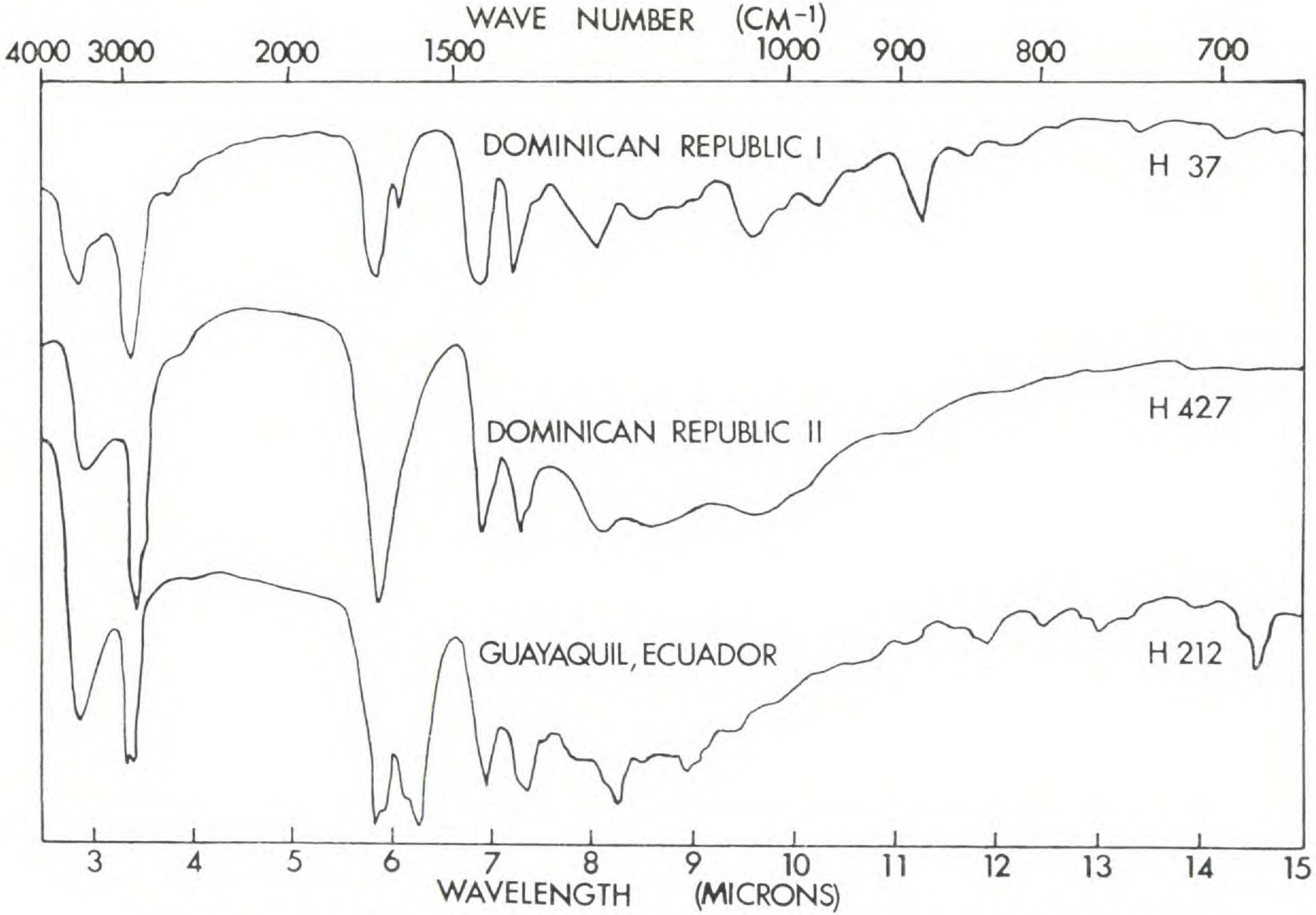
Infrared spectra of Oligo-Miocene amber from Chiapas, Mexico, Types I, II and III.

PLATE XXIV



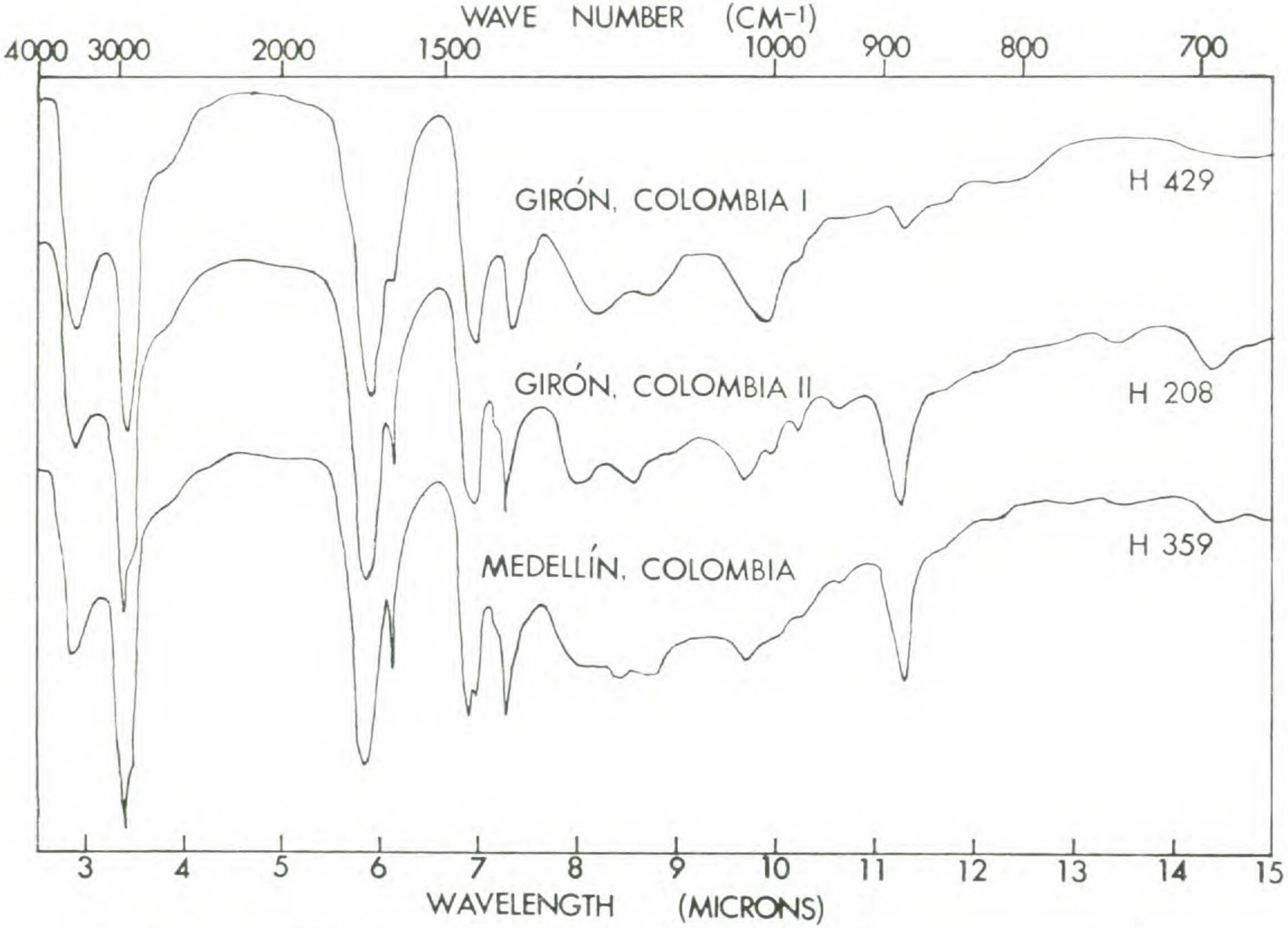
Infrared spectra of Eocene amber from Seattle, Washington, Types I and II and amber of unknown age from Cañon Diablo, Arizona.

PLATE XXV

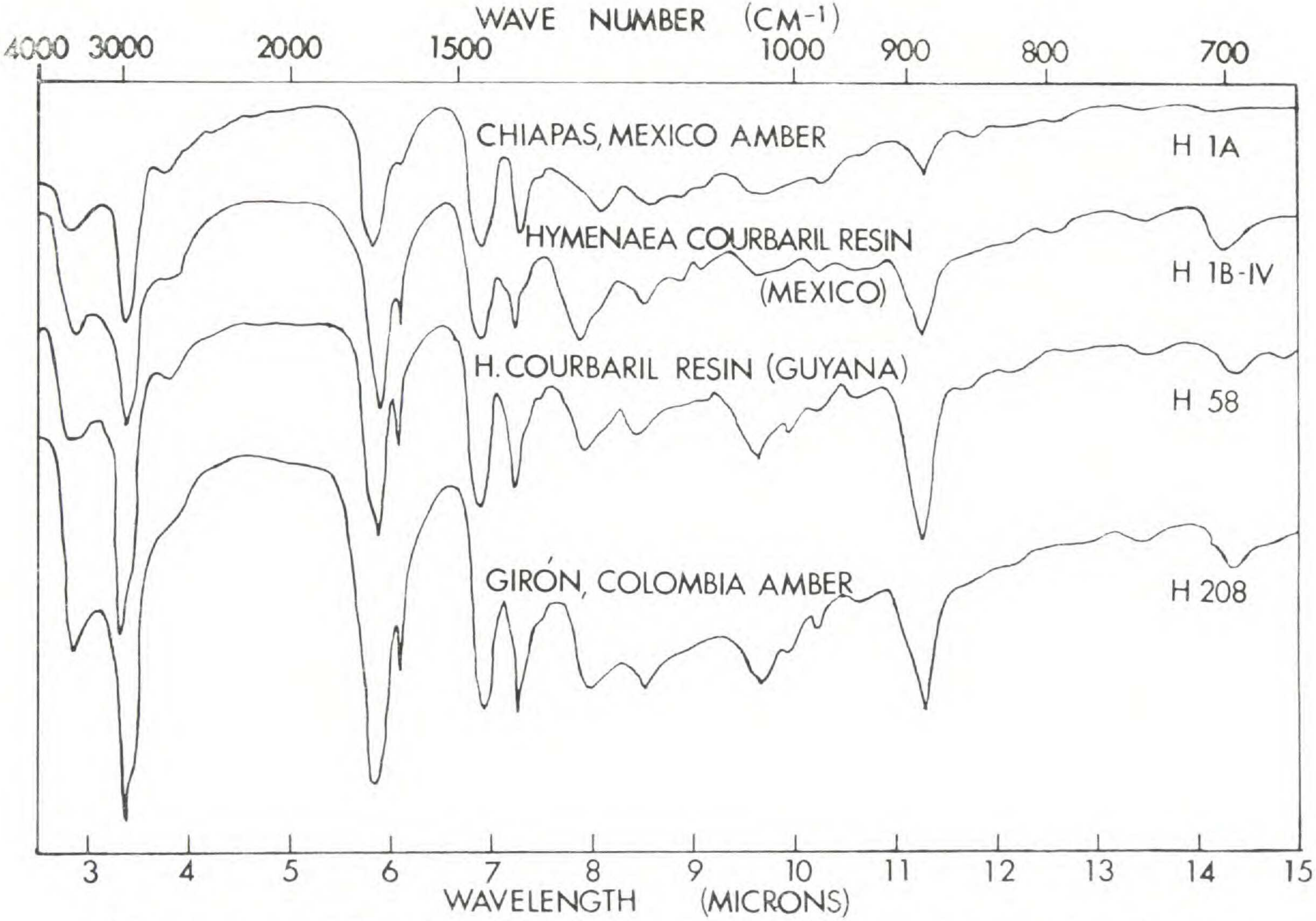


Infrared spectra of Oligocene amber from the Dominican Republic, Types I and II and amber of unknown age from Guayaquil, Ecuador.

PLATE XXVI

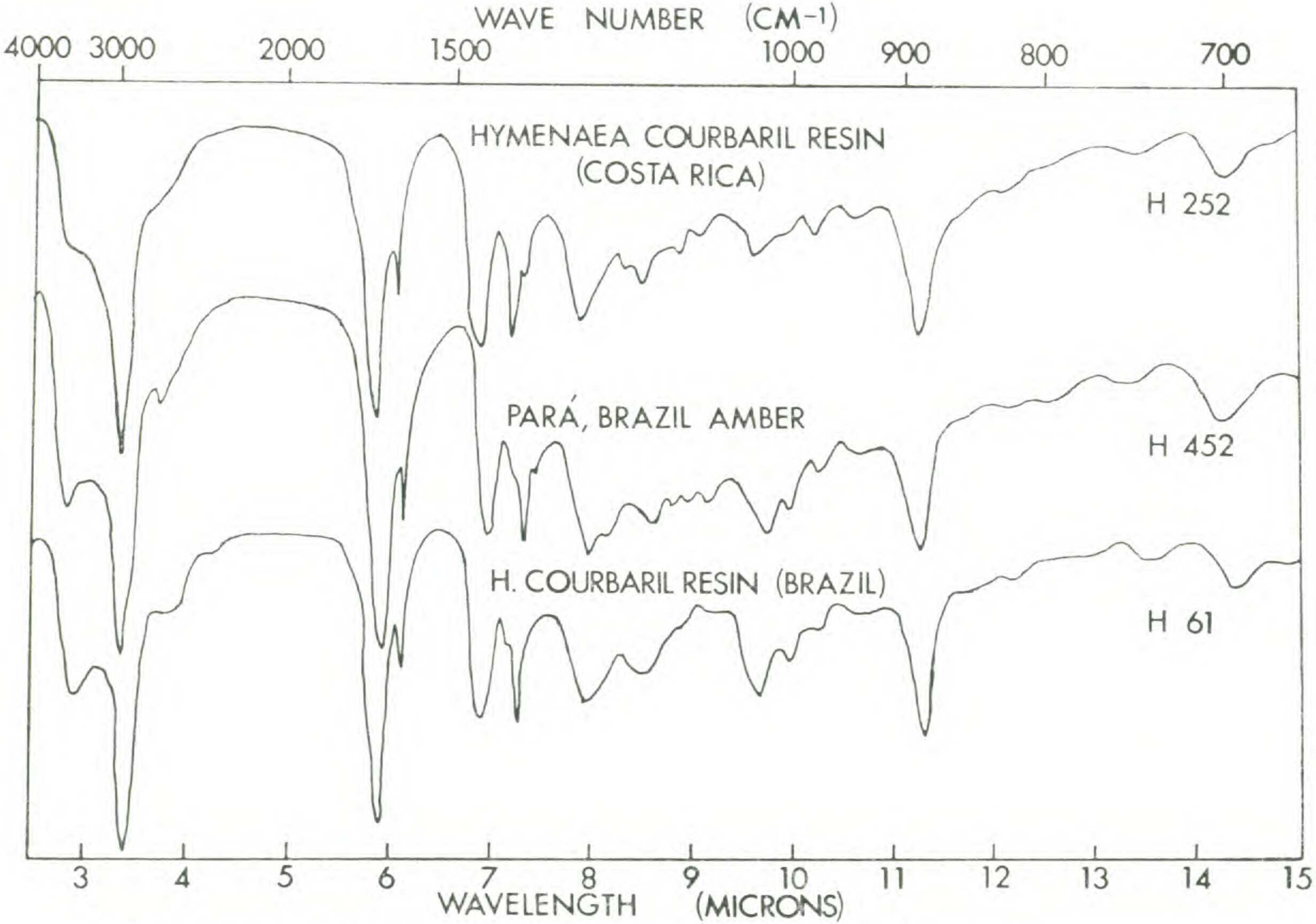


Infrared spectra of amber of unknown age from Girón, Colombia, Types I and II and from Medellín, Colombia.



Infrared spectra of Oligo-Miocene amber from Chiapas, Mexico, modern resin from *Hymenaea Courbaril* from Mexico and Guyana and, amber of unknown age from Girón, Colombia.

PLATE XXVIII



Infrared spectra of Miocene amber from Pará, Brazil, and modern resin of *Hymenaea Courbaril* from Costa Rica and Brazil.